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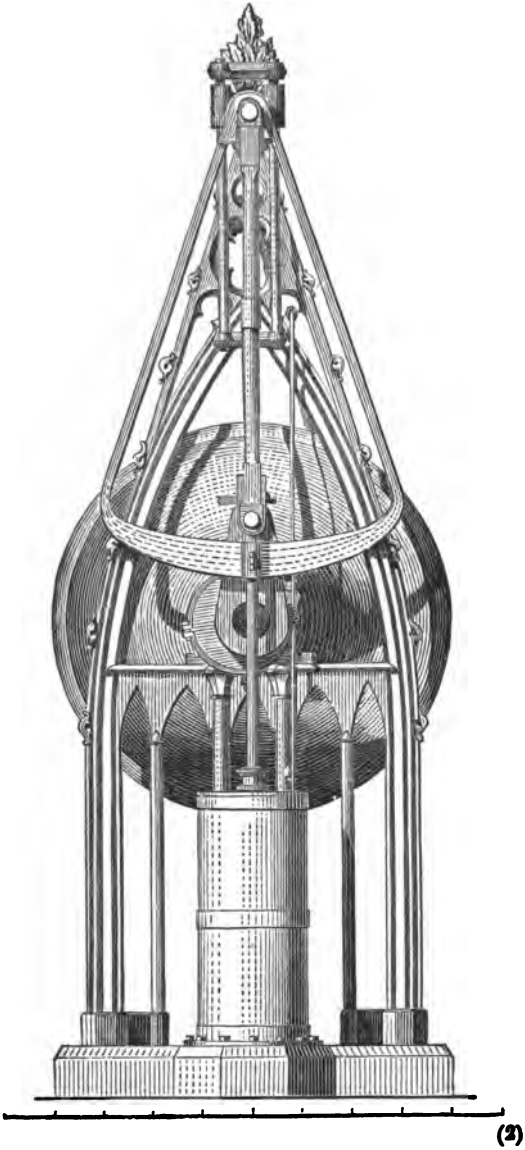

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MECHANICS

FOR

THE MILLWRIGHT, MACHINIST, ENGINEER, CIVIL ENGINEER, ARCHITECT AND STUDENT.

CONTAINING

A Clear Elementary Exposition

OF THE

PRINCIPLES AND PRACTICE OF BUILDING MACHINES.

BY

FREDERICK OVERMAN,

AUTHOR OF "THE MANUFACTURE OF IRON," AND OTHER SCIENTIFIC TREATISES.

ILLUSTRATED BY ONE HUNDRED AND FIFTY-FOUR FINE WOOD ENGRAVINGS,

BY WILLIAM GIHON.

PHILADELPHIA:

J. B. LIPPINCOTT & CO.

1864.

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PREFACE.

MANY mechanical laws are obscured by complicated mathematical formulæ, which embarrass the reader. I have endeavoured to dispense with these, in order to render the subject more attractive, but am conscious of not having arrived at the perfection at which I aimed.

It is my desire to be useful; and, as I am convinced of the great importance of Mechanics to the national prosperity, I selected this subject, with the view of rendering myself as useful as my abilities would permit.

THE AUTHOR.

PHILADELPHIA, June, 1851.

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MECHANICS.

CHAPTER I.

PHYSICAL LAWS.—INHERENT PROPERTIES OF MATTER.

WHAT IS MATTER? We cannot tell; no created being knows. We derive our first knowledge of matter from our senses. A consciousness of resistance in the objects by which we are surrounded, impresses us with a conviction of their substance; and from the different degrees of that resistance we ascertain the state in which matter exists. The touch will inform us of the relative rigidity of matter, and whether or not the component particles are movable. The sense of touch will thus establish a comprehensive scale of the form of matter, whether solid, liquid, or gaseous. The senses of sight and hearing will, after repeated experiments, enable us to judge of distant forms of matter, and thus teach us to substitute the indications of one sense for the experience of the other. The impressions produced by matter upon our senses, vary according to the capacity of those senses. If we touch the points of two or more needles, which are at some distance apart, with the points of our fingers, we may form a correct idea of this distance; but we should be unable to do so, were we to touch a large muscle with the needles. This specific

difference, which exists in various parts of the same individual, is quite as strongly developed in different persons. For these reasons, it is necessary to establish general expressions, based upon the general qualities of matter, as the marks by which specific qualities may be conveyed to our mind, and either elevate or diminish the sensitiveness of the individual.

THE ELEMENTARY FORM OF MATTER

Is a subject of little interest for our purposes. It does not influence our application of matter, if the ultimate particles are solids, incomparably harder than their compounds, as Newton believes them to be; or if the atoms are mere centres of forces, as others contend. Both these opinions lead to the same results — agree in the same principle; namely, "that the properties of matter depend upon forces emanating from immovable points." In our case, we have to guard against the impressions of the senses, which are apt to prejudice our convictions, and infect the mind with a relative property of ultimate particles. The atom of the diamond cannot be harder than the atom of water, or the elementary particle of the gentle breeze. The water-hammer, as well as the loud report of the whip, prove that the particles of air and water must be as hard as the particles of steel.

COMPOUND PARTICLES OF MATTER

Offer a marked difference to the constitution of primitive particles. While the latter are considered impenetrable by Newton, he asserts that the former are porous. Masses of matter are porous — full of void spaces. The atoms touch one another but in particular points. Some metals and other bodies may be compressed by mechanical force

into smaller spaces than they originally occupy; this, however, can be carried but to a certain point by such means, as there is an apparent limit to mechanical compression. All solids may have their particles approximated by cold; to this no limit has been ascertained. Matter in the abstract sense, or atoms, is impenetrable; it is solid and substantial. Matter in the relative sense, in compound atoms, is porous, fluid, and elastic. Mass is the quantity of matter composing the body.

THE QUALITY OF SOLID MATTER

Is expressed by its measurable differences in hardness, elasticity, brittleness, malleability, ductility, and compressibility. The diamond, hardened steel, iridium, tempered or soft steel, copper, lead, pine wood, &c., will convey a standard of comparison of the degree of hardness to our mind.

Hardness is that modification of matter which qualifies bodies to resist the effort to abrade their surfaces.

Elasticity is that property of matter which causes its particles to yield to a greater or less extent, if force is applied with an intention to change the relative position of the atoms. India rubber, steel springs, glass in plates or threads, hickory wood, &c., will convey an adequate idea of the comparative elasticity of matter.

Brittleness, the opposite of elasticity, is a quality of degree, not of kind. Very hard steel, and glass which has been suddenly cooled, are called brittle; so also an air-dried brick, which possesses much more of this quality than one which has been well-burnt.

Malleability is that quality of matter by which it may be extended in one direction by compressing it in the opposite; this may be effected by means of hammering, rolling,

or pressure. The metals possess this quality in a high degree.

Ductility is but a degree or form of malleability; it cannot be considered a specific quality of matter. If iron cannot be drawn into as thin sheets as gold, and still may be drawn into almost as fine wire as gold, it does not follow that there is a different kind of malleability in the two metals; it is the form of the matter which makes the difference in these cases. Most of the metals are ductile or malleable, others brittle, at the atmospheric temperature. All matter may be considered ductile under different degrees of heat. Glass is ductile when heated, and antimony and bismuth may be made ductile and malleable. Zinc is at common temperatures brittle, at a certain heat malleable, and beyond that heat brittle again.

Compressibility is a giving way of the atoms of a body to the influence of mechanical force. Some metals may be compressed by hammering, rolling, or squeezing, and do not return to their former bulk spontaneously.

LIQUID MATTER

Has properties analogous to solid matter. Elasticity is a common property, well developed in liquids. One million parts of mercury may be compressed 2.65 parts; alcohol, 21.65; water, 46.65; ether, 61.65. After the pressure is withdrawn, they return to their original bulk. A fluid is called *viscous*, if the particles are less movable; and *limpid*, if the atoms are easily separated. Molasses and oil are viscous; alcohol, ether and water, are limpid.

GASEOUS MATTER,

Or aeriform fluids, are generally divided into two classes, namely, vapours and gases; and it is asserted that steam

represents the first, and atmospheric air the second. This classification is imperfect, and leads to difficulties which can only be avoided by giving to gases and vapours the same general properties, and qualifying these by degrees. The difference is only one of degree, and not of kind. Gases are in the highest degree elastic. Atmospheric air has been compressed with all the ingenuity man can command; but he has never been able to compress it permanently; as soon as the pressure ceases, the air instantly expands to its former volume. Vapours of water do the same, provided we supply the heat which is liberated by compression, and generally absorbed by the vessel which contains the gaseous water. If mechanical pressure is assisted by the abstraction of the heat generated by compression, most of the gases may be permanently compressed, and transformed into liquids. Many gases may be compressed and transformed into liquids by simple absorption of heat. The conversion of gases into liquids depends upon temperature and pressure. While atmospheric air has never been condensed, carbonic acid condenses under a pressure of 525 pounds to the square inch, with abstraction of heat. Vapour of water condenses without any compression, by the abstraction of heat. Mercury does not require pressure, nor a sensible abstraction of heat, to condense and form a vacuum by common temperatures.

STRENGTH, OR COHESION,

Is the resistance which a body opposes to a separation of its parts. It is an internal force, inherent to the constituent particles of homogeneous matter, which attracts one to the other, with more or less force, at insensible distances. The strength of materials depends upon the close contact of their atoms, which nature accomplishes in so

perfect a manner, that art has not succeeded in imitating it to any high perfection. Two metal plates, if very straight and highly polished, will adhere firmly together. Glass plates, if ground and polished, will adhere so firmly, that they cannot be separated; this frequently happens in factories where glass plates are manufactured. The force which combines the globules of mercury, or the drops of water, is cohesion. This quality is very energetic in iron, but less so in silver, copper, or lead, and less in gases than in liquids. The cohesion may be destroyed by mechanical force; but the most effective means of overcoming it is by heat. The force which is required to overcome the particles is measured by experiment. It has been found that one square inch of cast-steel requires 140,000 pounds to tear it asunder; copper, 33,000; tin, 4,700; pine wood, 10,400; and water or air, no measurable power. The force which resists the tearing asunder is called *absolute cohesion*, or *absolute resistance*. Depending upon form is *relative resistance;* it is this strength which influences the force of breaking material; it is a compound strength, formed of the first and the next following. The *resistance to compression* is the modulus of that force by which a body may be crushed. It has been ascertained by experiment that a cube of cast-iron, of one-fourth of an inch sides, may be crushed by a weight of 10,000 pounds; brass by 10,304, oak wood by 950, and pine by 400 pounds. A fourth class of cohesion is the *resistance to torsion;* in this, absolute cohesion is the most active force.

The laws of cohesion are modified by heat and motion. The latter will diminish it, and heat will destroy it effectually. If a band of metal be stretched by weight to its utmost limit, but not so far as to injure its cohesion or stretch it permanently, and a vibratory motion be given to

it, it will become permanently lengthened. We may illustrate this by taking a strip of copper three yards long, ·4 inch wide, and ·04 inch thick, and suspending it with a weight of ninety pounds attached; if motionless, it will remain unchanged for any length of time; but if it be made to vibrate, it will become six or seven inches longer. A bar of wrought-iron will finally break, if suspended and stretched by weight, when repeated blows with a hammer are applied to it.

ADHESION

Is the tendency of different kinds of matter to adhere together. If we dip a glass rod in water, we have an illustration of this quality in the water adhering to the rod. We can estimate the amount of force required to overcome this adhesion by the weight of water which may be raised by its influence.

This attraction of heterogeneous matter exists in different degrees between different bodies, though perhaps between some bodies it does not exist at all. Water has a great affinity for iron, and more for glass; but to neither of these substances will mercury adhere. A clean surface of platina may be covered with mercury; but the latter will not adhere to it.

Chemical affinity appears to be an agent in promoting the force of adhesion. Gold requires 446 times its own weight, zinc 204, and iron 115, to overcome the adhesion of mercury.

Adhesion is one of the impediments to motion; and we shall therefore mention it again in treating of *friction*. The action of cements in permanently fixing the surfaces of solids together is also mainly dependent upon this force. *Capillary attraction* is caused by adhesion; it is in many

cases sufficiently strong to overcome gravitation, and even the force of homogeneous attraction, or cohesion. This power increases in a high ratio inversely to the distance, and appears to follow the same law as heat, light, magnetism, &c. The absorption of water by a piece of sponge, or by clay, cotton, silk, hemp, and other substances, is caused by adhesion. The rising of oil in a small bundle of wire, or in a cotton-wick, is the result of adhesion. The ascension of the sap in trees and vegetables is also attributable to adhesion. A prodigious amount of active force may be called into motion by it. A dry plug of wood fitted tightly into any orifice, and then wetted, will burst any tube or vessel, no matter how strong it may be.

The attraction between gases and glass is remarkably strong; it is less between gases and metals. This circumstance is of some importance in constructing hydro and pneumatic machinery. Porous solids not only absorb gases by capillary attraction, but absorb and condense in a high degree. Charcoal will absorb 90 times its volume of ammonia, 35 times its bulk of carbonic acid, 7·5 that of nitrogen, and 1·7 of hydrogen.

WEIGHT, OR GRAVITY,

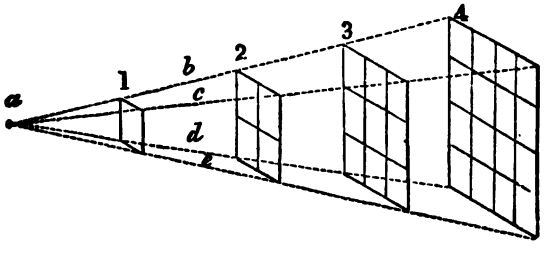
Is the force which attracts masses of matter at very great distances from each other. This force is exemplified in the fall of a body to the earth, and by the approach of two bodies towards each other, which will happen if they are free to obey the impulses of their gravity. A plummet suspended on a string shows the direction of gravitation; this direction is towards the centre of the earth, and is perpendicular. If a plummet is suspended by the side of a mountain, it deviates from the perpendicular, and the direction of gravity is not towards the centre of the earth,

because the plummet is measurably attracted by the mountain. Gravity does not belong to the larger masses of matter only; it is an inherent quality of all matter — it belongs to the atom as well as to the mountain; to the distant planet, as well as to objects with which we are familiar.

The intensity or force of gravity is different in different latitudes. It is measured by the velocity of a body moving in the line of gravitation, free from any impediment. The velocity in our latitude is 16·09 feet, or nearly 16 feet 1 inch, during the first second of the fall.

The law by which one body is attracted by the other, is in the inverse ratio of the squares of the distances of their centres. As this law regulates all the known forces which emanate from a centre, we illustrate it most successfully by the following diagram. If, in fig. 1, *a* represents the centre of a mass of matter, 1, representing one distance, will

Fig. 1.



be equal to one attraction. At 2, meaning two distances, the power *a* has to act upon four surfaces like 1; its attraction is therefore diminished. At 3 it has to act upon nine, and at 4 upon sixteen surfaces equal to 1. If, instead of gravity, we take a lighted taper to be in *a*, and a board one foot square be held in 1, the shadow of the board in 2 will

be four square feet, in 3 it will be nine, and in four it will cover sixteen square feet. If the candle is to throw the light upon one foot square, the rays *b c d e* will be four times as much concentrated upon 1 as upon 2, or four feet square; nine times as much expanded upon 3 feet square, and sixteen times as much as upon 4 feet square. Straight boards are not segments of spheres, as they should be. The foregoing figure is merely intended as a simple practical illustration.

PENDULUM.

If a body be freely suspended by a string or rod from a fixed point, it will point to the centre of the earth, and remain stationary. If we move the body, it will rise in the arc of a circle, of which the fixed point of suspension is the centre. When its moving force is exhausted by the counteracting force of gravitation, it will immediately begin to descend in the arc in which it was raised by the applied force. When the body arrives again in its vertical position, it will have acquired a momentum which will carry it forward in a direction opposite to the first, from which it will return in a certain time. This motion would continue any length of time, and last for ever, if friction and the rigidity of matter did not prevent it. The number of oscillations thus made in a given time by a pendulum depends partly upon the amount of gravity, and is greater at the poles of the earth than under the equator. The number of vibrations in equal times is inversely proportioned to the square root of the length of the pendulum. A pendulum which beats seconds is nearly 39·1 inches long. Masses, suspended in the manner of a pendulum, may acquire an immense momentum by the application of a small moving force, whose impulses coincide with the time and direction of the oscillations.

ABSOLUTE WEIGHT,

Or weight simply, is gravity in its general bearing; it is an exact amount of force, expressed in relation to some known standard. If the force of gravity expressed in such a standard weight is counterbalanced by a force exactly representing the same weight, the latter will effect a suspension of gravity in the body, and prevent that body from falling to the ground.

The standard weight of this country is a pound troy, equal to 5760 grains, or a pound avoirdupois, equal to 7000 grains. The weight of a body, as it depends upon gravity, is variable according to its distance from the centre of the earth. On high mountains, a pound will not be as heavy as it is on the sea-coast. The difference is small, and, at the height of 10,000 feet, scarcely amounts to one ounce in a hundred pounds. Between the equator and the poles, however, there is a greater difference; 194 pounds at the former are equal to 195 pounds at the latter.

SPECIFIC WEIGHT, OR SPECIFIC GRAVITY.

Every substance occupying a given space has, under the same circumstances, a weight peculiar to itself — a specific weight. The same volume of different kinds of matter contains more or less absolute weight. A measure of one kind of matter may be 17,000 times as heavy as a similar measure of other matter, as is the case between platina and atmospheric air, and still both perfectly fill the space which they occupy.

The specific weight of various materials differs very considerably. As a standard of comparison of the specific gravity of solid and liquid bodies, water has been selected; for gases, atmospheric air is the standard.

HEAT,

The most hidden cause of all our physical sensations, is also, as we have already remarked, the most effective antagonist of cohesion, and the most repulsive of all forces. One of the most common actions of heat is its power of expanding all matter, and ultimately destroying its cohesion effectually. The principal source of heat is the sun, the direct rays of which are sensibly felt. Whether or not the sun's rays possess and distribute heat directly, or merely awaken the dormant heat of our globe, it is not our province to determine; it has no bearing upon our calculations. It may, however, be of interest to know, that if we were to burn every combustible on the face of the earth, it would not be sufficient to supply the loss of twenty-four hours of the sun's rays. Whenever the sun is above the horizon of any place, that place is receiving heat; when below, it parts with it by the process of radiation.

Another source of heat is combustion; a chemical process which, under certain conditions, emits both light and heat. A third source of heat is friction; it is apparently a modification of the second source. In this case, mechanical force is opposed to the forces of cohesion and adhesion, and heat is generated by the reaction of the two. When glass and cork are rubbed together, the former will exhibit 34, and the latter only 5 parts of heat. Silver and cork compare as 50 to 12. Two pieces of dry wood speedily ignite, if rubbed together. The sparks emitted by steel when rubbed or struck on flint are also caused by friction; the once generated heat in the small chip of steel is continued and increased by the burning or oxidizing of the particle. Grindstones frequently exhibit a profusion of such burning sparks of iron or steel, if the metal is held on

them when dry, and in rapid motion. Electricity also generates heat; but this may safely be considered as allied to the second source. We possess, in common with all animals, a source of heat in ourselves; this also we refer to the operation of the second cause of heat.

What heat is, is a question which does not interfere with our investigations; all we want to know is, what are its sources and effects.

EXPANSION.

Heat does not affect the direct weight of matter; but it disturbs its specific gravity, by increasing the volume of bodies. The increase of bulk differs very materially, in different substances, by the addition of the same amount of heat. Thus, solids do not expand as much as liquids, while the expansion of gases is greater than that of either solids or liquids. Lead expands in volume, by being heated from the freezing to the boiling point, 1 in 350 parts; iron, 1 in 800; water, 46 in 1000; and air, in the same range of temperature, augments its volume from 1000 to 1373 parts. When the heat is withdrawn, the bodies, with but few exceptions, return spontaneously to their former dimensions.

A true measurement of the quality or intensity of heat in low temperatures is afforded by the thermometer; for higher degrees of heat, Daniell's register pyrometer is quite effectual. The scientific men of our time have not yet agreed upon a general thermometric scale. The United States and Great Britain divide the space between boiling and freezing into 180 parts, and add 32 below freezing. France divides the space between freezing and boiling water into 100, and Germany into 80 degrees. This arrangement is inconvenient for scientific purposes; but the

conversion of one scale into another is not at all difficult. The register pyrometer of Daniell answers all the purposes beyond the reach of the thermometer. Wedgwood's pyrometer is out of use at present, and indeed has never been of any benefit to science or art.

It has been ascertained that the expansion of solids by equal degrees of heat, compared with that of air, increases as the heat rises. The expansion of iron increases from 212°, where it is $\frac{1}{371\frac{1}{20}}$, up to 702°, to $\frac{1}{311\frac{1}{300}}$ spaces more than air.

The expansion produced by heat is the most effective and most powerful source of forces. If a bar of metal is heated, it will move almost any obstacle in its way, and in contracting after the heat is withdrawn, will carry every burden, no matter how heavy, if the reacting force is not greater than the cohesion of the metal. An iron hoop or wheel-tire will finally break, if it be too short, in the process of fastening it to the wheel. We have a well-known illustration of this force in drawing the tire of the wheelwright, the hoop of the cooper, and the rivets of steam-boilers. Architects have not been slow to perceive the utility of this force, and have applied it in restoring leaning walls to their vertical position, or raising sunken arches. In working in metal, it is of great importance to make allowance for the operation of this law; indeed, too much attention cannot be paid to it. In buildings where stones and iron are simultaneously employed, it has been found of serious consequence if the difference of expansion of the two materials was not properly taken into consideration. The expansion by heat is a very important coefficient in the construction of metallic bridges.

FLUID MATTER

Expands much more than solids, and the expansion is generally regular, if not too near the boiling or freezing point. Water and a few metals form an exception to this rule; for water expands a few degrees above congelation, at about 40°, and increases in bulk until it solidifies. Cast-iron, sulphur and antimony show the same apparent anomaly. Mercury expands from freezing to boiling 1 in 555, water 1 in 23, and alcohol 1 in 9 parts.

GASES

Expand still more than fluids. Their expansion is so regular, that for each degree of the thermometric scale it is 1 in 480 parts. If a certain amount of air or gas occupies 480 spaces at 32°, it will occupy 481 spaces at 33°, and at 100° it will have grown to 548 parts.

CONDUCTING OF HEAT.

If we take a piece of charcoal and hold it in a flame, or heat it at one end, we find no disagreeable sensation from the effects of heat, even if our fingers are close to the burning point. If we take a piece of metal rod, or wire, however, and apply it to the flame, the heat will soon reach our finger, though the metal rod may be many times longer than the piece of charcoal. The relative speed with which heat travels through a body, or is conveyed along the metal, is a specific property of matter which is of important practical consequences. The range or time in which different materials conduct heat is very different in various elements, and appears to be stronger in those which are most dense. Metals conduct heat most perfectly; then follow

stones, hard wood, soft wood, and fluids. Gases, when not in motion, are the most imperfect conductors of heat. If gold has the capacity of conducting 1000 parts of heat to a certain distance in a certain time, iron will conduct 374, lead 179, and fine clay but 11 parts to the same distance in the same time. This quality of matter accounts very satisfactorily for the different degrees of sensation of which we are conscious in touching different articles in the same room, or under the same degree of heat. A piece of gold will conduct all the difference of heat between itself and our muscle, or part with its heat, in a much shorter time than either iron, brick, clay, or air.

LIQUIDS

Conduct heat very imperfectly, and it is doubtful in many instances whether they conduct it at all. They acquire heat, however, with great facility; and we are liable to conclude from this, often too hastily, that liquids are conductors. The facility with which liquids absorb heat does not depend upon their conducting capacity, but upon their motion. Very little heat is absorbed by liquids which are at rest. It has been ascertained by very delicate experiment that mercury is a better conductor of heat than water, and that water is better than oil; but the difference is so insignificant, that we are permitted to overlook it in our practical applications.

GASEOUS BODIES,

Or aeriform matter, are inferior as conductors of heat to liquids. We may safely conclude that air does not conduct heat at all. A piece of metal heated to 110° or 120° of Fahrenheit's scale will inflict a severe burn; but water heated to 150° will not scald us, provided there is

no motion; and we might remain for hours in a room heated to 300°, if we did not move. A thin layer of air or liquid is sufficient to protect us against the influence of the surrounding heat. The same quality of gaseous and liquid bodies which protects us against the influence of heat, serves also to screen us from the cold, or it would be difficult to account for the well-being of travellers in the arctic regions, where the thermometer falls below —50°, or below the freezing point of mercury. Animals may sustain excessive heat or cold without danger or difficulty, provided there is little or no motion in the air. There is no difference between the vapours of liquids and atmospheric air in their conducting power. We may put a moistened hand into melted metal with impunity, provided we do not move the hand. The latter assertion is easily proved by throwing a few drops of water in a cavity of red-hot iron; the water will gather in the cavity into one globule, and, if the cavity is very concave and the metal very hot, it will take a long time before the water is evaporated. The temperature of the water does not rise to boiling; the thin layer of steam between the hot metal and the water preventing the access of heat to the latter. At a lower heat of the metal, water evaporates readily. We must not conclude from this that simple air or gas is the best non-conductor in practical operations. On the contrary, we find in practice that flax, cotton, wool, eider-down, &c., are still worse conductors than air. This exception to the law, however, is only apparent; for it is the air "at rest" in such matter which gives it its non-conducting properties. Practically, it is very difficult to prevent air from moving, and in proportion to its motion it will conduct heat.

CIRCULATION OR CONVECTION OF HEAT.

Notwithstanding the difficulty with which heat travels through liquids and gases, we find that both kinds of matter become speedily heated. The process by which liquids are thus rapidly heated is circulation, or owing to a rapid change of particles in their relative position. When a liquid is heated it becomes expanded, and its specific gravity is diminished. The great mobility of liquid particles will bring those which are lightest to the surface of the liquid, and in consequence a new portion of cold fluid is brought into contact with the source of heat. The whole of the liquid is in this way brought into close proximity to, or contact with, the generator of heat; and all the particles will be successively under its influence. It is natural to conclude that, the more liquid is exposed to fire, the higher the column of the liquid, the greater will be the difference in the specific gravity of the upper and lower strata of fluid, and the more rapid will be the circulation caused by heat. Any tenacity, viscosity or sliminess, will retard the circulation of the fluid, and cause a delay in the conducting of heat. We need not be surprised at finding that farinaceous substances retain their heat longer than clear, limpid liquids.

Gaseous matter conducts heat by convection still more rapidly than liquids. There are less disturbing causes of circulation in gases than in liquids; still, the disturbing effects may often be so strong as to defeat our attempt to conduct heat. If we place a candle in a bell-jar, and prevent the access of air from below, covering the top so that but a small opening is left, the candle will be extinguished; for the ascending current is strong enough to prevent the descent of fresh air. If we make a second hole, or insert a

glass tube in the first hole on the covered top, which does not quite fill it, the candle will burn until it is consumed. We have daily practical illustrations of the convection of heat in gases, in the action of our chimneys, and the circulation of air in dwellings and in mines. We may observe it at the top of a lighted candle, and in the ascending current issuing from a hot poker. The natural ascent of convected heat is vertical, but may be conducted by tubes in any desired direction. The rarefied particles will always form the upper stratum, while the denser atoms will assume the lower position.

HEAT OF COMPOSITION, OR SPECIFIC HEAT.

Equal volumes of the same liquid, of different temperatures, mixed together, afford the mean temperature of the two. Thus, a measure of water at 50°, and another at 70°, mixed together, will afford two measures of water of 60°. If we mix a measure of water of 40°, however, with an equal measure of quicksilver at 100°, it does not yield a mixture of 70°, but is lower, or only 60°. The quicksilver loses 40°, while the water gains but 20°. This apparent anomaly is still more striking, if we take equal weights instead of measures. The water contains here the whole heat which the mercury lost; still, it does not show it—we can neither feel nor measure it. Hence it appears that water requires more heat, or has a greater capacity for it, than mercury. This is further evident from the fact that a greater heat is required to raise water to 10°, than will suffice to raise the temperature of quicksilver to the same point.

Analogous differences exist between other kinds of matter, as between mercury and water, varying only in degree. Thus, if a certain amount or weight of water requires

1000°, hydrogen gas needs 3293, air 266, iron 113, and gold only 29, to raise the same quantity of these various materials to the same degree of heat. The capacity for heat increases with the rising temperature, which, however, is so small a difference, that we may safely neglect it. To the difference in the specific heat of matter according to its density, is owing the elevation of temperature by compressing it; and the opposite effect is shown by expansion. If two liquids of different specific heat are mixed together, the temperature will rise in consequence of a condensation of the liquids, provided the liquids condense. The sudden compression of air liberates heat, and its sudden expansion absorbs it, or produces a sensation of cold. The heat generated by compression is very important, and the reverse must be expected if expanded. It has been found by experiment that air compressed into one-third of its original volume will liberate 120°, or, what is the same, raise the temperature of the compressed air 120° higher than it was when expanded. The same amount of heat will be absorbed if the compressed and cooled air recovers its former density, or is expanded three times.

LATENT HEAT.

If matter undergoes an important change, as from the solid to the liquid, or from the liquid to the gaseous state, it absorbs heat which is not measurable by the thermometer. In matter which is condensed, on the contrary, there is a sensible liberation of heat. If we mix a weight of ice at the thawing point, 32°, with one of water at the boiling point, 212°, the mixture does not produce two weights of 106°, as might be expected, but only two weights of 52°. The ice gains here but 20°, and the water loses 160°; the remainder, 140°, is lost in changing the solid ice into

liquid water. This heat is not lost, but given out again, if the water is converted into ice. Similar phenomena are observable in all cases of liquefaction; the amount of heat fixed and liberated is not so great as in water, but the fact is everywhere perceptible. Freezing mixtures depend upon these principles.

The absorption of heat is most striking in the evaporation of liquids. If we assume that one weight of water requires 180 heat to raise its temperature from 32° to boiling point, or 212°, it will require 950 + 180 = 1130 heat, to make steam of 212°; 950 parts of heat are expended to convert the liquid into a gas. All liquids remain perfectly fixed at the temperature of their congealing points during the process of liquefaction; that is, so long as any solid substance remains. The temperature of such liquids cannot rise, because all the heat to which it may be exposed is absorbed, and rendered latent or insensible. The congealing point of various liquids is very different. Iron congeals at a temperature of 3280°, copper at 1996°, lead at 612°, and mercury at —39°; water at 32°, and sulphuric ether at —46°. When liquids pass into the solid form, their latent heat becomes perceptible.

EVAPORATION.

If the absorption of heat is important in liquefaction, it is still more so in evaporation. The fixing of heat is so important, that the most excessive admission of heat to the fluid never raises the temperature beyond the boiling point, provided the formed gases are permitted to mingle with the atmosphere, or escape. Every liquid, under the same conditions, invariably boils at the same or its own temperature. The boiling temperature is modified by heavy impurities, solutions of salt, and pressure beyond the com-

mon atmosphere; an influence of this kind will raise the heat necessary for evaporation. Admixtures lighter than liquid water, such as alcohol, ether, and acetic acid, mixed with water, by the diminution of pressure on the surface, lower the boiling point of liquids.

The quantity of heat absorbed in evaporating liquids is very large, as shown above. The liberation of heat in condensing gases is equally large; for, in the case of water, we find that one gallon converted into steam will heat five and a half other gallons of water from 32° to 212°. Under a decrease of atmospheric or other pressure, the evaporation is rapidly increased. The decrement is in the ratio of the diminished pressure. This is a very important subject in practical investigations, if not in its bearings upon results, at least as a principle. In removing the raised vapours of the liquid, water may be boiled at almost any temperature below 212°. In proportion as the pressure upon the surface of a liquid increases, its boiling point is raised. Water will boil at 212° under common pressure; but it requires 250° by doubling the atmosphere, or, what is the same, raising a pressure of steam to sixteen pounds; 350° would be necessary with a pressure of 150 pounds to the square inch.

THE DENSITY OF VAPOURS, OR GASES,

Increases directly with the applied force of compression, or with the pressure to which it is exposed. Whatever its density may be, the same weight always contains the same amount of heat. The latent heat increases as the sensible heat diminishes, and the converse of the rule is equally true. Steam at a temperature of 212° is composed of 180° sensible, and 950° latent heat = 1130°. Steam of 250° shows 218° sensible, and 912° latent heat=1130°. Steam

of 100° shows 68° sensible, and 1062° latent heat = 1130°. Amongst all liquids, water shows the greatest capacity for heat; but in the mean time it undergoes a much greater expansion of volume than any other liquid known. The liquids alcohol, sulphuric ether, and spirits of turpentine, are specifically lighter than water; but their vapours are by far heavier. Thus, one cubic foot of water gives 1689 cubic feet of vapour, under common pressure; one cubic foot of alcohol, 493 feet; one cubic foot of ether, 212 feet; and one cubic foot of spirits of turpentine, but 192 cubic feet of gas or vapour.

It has been proposed, for the purpose of generating mechanical power, to make use of the vapour of more volatile liquids than water; but if we compare the density of such vapours, and the consequent small effect of the same weight of fluid, and add to this the capacity for heat of such liquids, we find that water is the most advantageous. One cubic foot of water yields, say 1700 feet of steam, and its latent heat may be 1000°; one cubic foot of alcohol yields 493 feet of vapour, and its latent heat is 457°. Now, if to produce 493 feet of alcoholic vapour we require 457 parts of heat, then for 1700 of vapour we shall require 1575 of heat. Water requires only 1000°+180°=1180°. Other liquids show still less favourable conditions than alcohol. It is clearly shown by such calculations that water is the most advantageous fluid for generating power, because of its large expansion when converted into steam.

Vapours or gases are formed by any degree of heat, so long as liquids are not solidified. Water evaporates very rapidly at common temperatures; mercury also evaporates, and we may conclude that every liquid, without exception, does the same. This tendency of one kind of matter to mix with another is beautifully illustrated in the *endosmose*,

or "flowing in," and the *exosmose*, or "flowing out," of gases and liquids. If we take a glass funnel, and tie over its mouth a piece of bladder, and fill it with spirits of wine; and then if we attach a glass tube, three or four feet long, to the neck of the funnel, and place the whole in a vessel of water, the bladder being undermost, and resting upon a piece of perforated tin plate; we shall find, in a short time, that the liquid will begin to rise, and, notwithstanding the accumulated pressure in the glass tube, will finally ascend to the top and flow out of it. We have here a combination of known powers which illustrate the phenomenon; it is the adhesion of the bladder to the water, and the affinity of the alcohol for that element, which cause the ascent of the liquid. The same phenomenon is shown in a varying degree by all matter. Metals and glass are hardly sufficiently impenetrable to enclose one kind of gas; the gas or matter which surrounds it will finally find access to the interior. A globe of cast-iron, of two feet diameter, accidentally broke, in which a cavity was found to exist, caused by the contracting power of the iron; the cavity was filled with water, when the otherwise solid globe of iron was broken.

The diffusion of matter is traceable in liquids and gases, and differs only in degree; it appears to be a general law of nature. Vapour is not only formed at boiling points, or when the pressure of the air or its own atmosphere is removed; but evaporation proceeds at all temperatures, however low. Such spontaneous evaporation is mostly confined to the surfaces of liquids, and is therefore slow, and in proportion to those surfaces. If the surface of the evaporating water is covered with oil, the water will cease to evaporate until the oil is destroyed. This kind of evaporation does not proceed so fast when the air is still as when

it is agitated; a strong wind increases it remarkably. The temperature of the atmosphere also has influence upon it. While, at the temperature of 75°, but three parts of water could be evaporated in a calm, nearly six parts were evaporated at the same temperature by a high wind. While eight parts were evaporated at 85°, but one part was converted into vapour at 25°. For the purpose of producing a vigorous evaporation, it is not necessary to have a relative vacuum over the liquid to be evaporated, or an excessive circulation of air; it is sufficient if the vapours of the liquid which is to be evaporated are removed, or if the atmosphere which covers the liquid is of a different nature from that generated by the liquid itself. Water evaporates very slowly if the newly-formed vapours are allowed to remain over the liquid; the evaporation goes on faster if the surface of the water is brought into renewed contact with air, or with a gas which has great affinity for water-gas. Dry air is a very strong absorbent of the vapours of water. The effect of this kind of evaporation is based upon the principle of the endosmose and exosmose, or the general tendency of one kind of matter to mix with another of a different description.

CONDENSATION OF GASES.

Almost all gases, with very few exceptions, can be condensed into liquids by means of pressure and cold. This condensation, and the subsequent expansion, of these liquids, has been applied for generating mechanical power; but the cold produced in consequence of the expansion of such liquids has been a serious obstacle, and sufficient to cause a discontinuance of such experiments. Liquids can be converted into vapours of such density, that the differ-

ence of specific gravity is annihilated. Water requires about 600°, and assumes four times its original bulk; alcohol 400°, with an expansion of three-fifths.

RADIATION OF HEAT.

Heat, the cause of life and the immediate source of motion, is not entirely subject to matter, at least not in the common sense. Heat can detach itself from matter, and project itself through space with a velocity beyond human comprehension. This property is known under the name of radiation of heat; it tends to produce that state of equilibrium of temperature between distant bodies, which we find and recognise by conducting and convection of heat between bodies in contact. We recognise radiation in the greatest perfection from the sun. The laws of radiation are similar to those of attraction, or gravitation, and other agencies of motion. The intensity of heat decreases in an inverse ratio to the squares of the distance, though the law is to be modified in some of our practical applications. Radiating heat is subject to all the laws and phenomena of light, merely modified by intervening matter; and as the laws of motion of light are more cultivated than those of heat, but do not belong to our province, we allude to it chiefly to draw the attention of those who wish for more information to these facts. Radiating heat is able to pass through but few substances, as it is arrested by the greater number. Heat will pass through glass without obstruction, while it is perfectly absorbed by charcoal. It is well known that the direct rays of heat are more absorbed by dark bodies than by light or coloured matter, and that dark colours absorb more heat than lighter tints.

TRANSMISSION OF HEAT.

Bodies which are more or less transparent, transmit heat in a degree often not in seeming conformity with preconceived notions. A far greater amount of heat is transmitted through rarefied air, than through that of a denser quality. A dense liquid of the same kind absorbs more heat than a liquid of less specific gravity.

The transmission of heat appears to be related to the intensity and quality of light with which it is combined. The heat of the solar rays passes through well-polished glass almost unobstructed, while the heat of terrestrial radiation is almost wholly arrested. The rays of heat follow in all respects the laws of radiation; but we observe a difference between the solar rays and those of artificial origin. Glass lenses and concave mirrors easily concentrate the heat and light from the sun, but do not increase the effect of radiation from our own fires. The white metallic mirror reflects and concentrates sidereal and artificial rays with equal facility. The most intense rays of artificial heat may be successfully arrested by the interposition of a thin glass plate; a succession of glass plates will annihilate radiation entirely. The hydro-oxygen flame emits scarcely any light, and does not radiate heat; but if a white body is held in the flame and light produced, the flame will from that very moment radiate heat. After all these apparent differences between solar and artificial heat, we are not permitted to assume that there is a difference in their nature, or that the difference between them is any more than of degree.

The power of bodies in transmitting heat is not proportioned to their transparency, or ability to transmit light. Crystallized bodies and foliated matter intercept most of

the rays of heat. These properties are more observable at low than at higher temperatures. While rock-salt permits 92 rays to pass, glass transmits but 50, alum 12, and distilled water 11 rays. This difference of bodies in permitting the passage of heat appears to arise from a difference in the aggregation or mechanical form of matter. If rock-salt is split into flakes, its capacity for transmitting heat is nearly destroyed. All bodies which transmit heat are less affected by it, and do not show so much increase of temperature, as those which conduct it less perfectly. The power of transmission varies not only in different materials, but also according to the source whence the heat is derived. Rock-salt appears to transmit at all times a certain amount of heat, 92 per cent., no matter from what source the heat is derived. Glass transmits 39 rays from a common flame, 24 from platina, 6 from hot copper, and no heat at all from copper which has been heated only to the boiling point, and blackened on the outside. Pure ice transmitted six rays from a flame, but no heat whatever from metals. In passing the rays of the sun first through clear, and then through green glass, the whole of the heat may be separated from the light. The effect of radiated heat from different colours is very striking. If the rays of the sun fall upon some dark body, and are reflected from this upon some lighter substance, the effect of the heat from the secondary source is far greater than from the sun directly. If a glass tube containing water be exposed to the rays of the sun, we perceive but little effect; but if we place a blackened reflector behind the tube, and reflect the heat from this, we very soon perceive a change of temperature in the liquid.

NATURE OF METALS.

The metals constitute a well-known class of substances, and are generally easily recognised. They are chemical elements, and belong to the combustible class of matter. They are good conductors of heat and electricity, and they fuse, or are converted into liquids, at different degrees of heat, according to kind. Metals volatilize at a still higher heat than that at which they melt, and, with the exception of quicksilver, are all solid at common temperatures. Their most characteristic quality is their lustre. They differ in hardness; some will scratch glass, such as iron, titanium, iridium, and manganese; others may be cut by the finger-nail, such as lead, tin and potassium. Most of the metals assume, in cooling, a well-defined crystalline form, which is in some measure injurious to their strength. The less the crystalline form is developed in a metal, the greater is its cohesion. Specific gravity is in most of the metals greater than in water; but in some, as in potassium, it is smaller. The specific gravity of platina is twenty times greater than that of water.

Another characteristic quality of the metals is their capacity for conducting heat and electricity; this quality is so well developed, that a comparison between them and other matter is inadmissible. Iron, the very worst conductor among the metals, has four million times the conducting power of water. As the conducting power of matter for electricity is equal to its conducting power of heat, with slight variations, it is advisable to investigate the first, because it has been more fully experimented upon than the latter. We find that electricity, and consequently heat, is conducted with the capacity of 60 for silver, 38 for lead, and but 8 for wrought-iron. Copper and iron conduct in

the ratio of 12 to 5. The conducting power increases in the direct ratio of the mass.

Metals, with but few exceptions, are malleable and ductile; some can be drawn under the hammer to a considerable extent; others break, and may be pulverized. Most of the metals have to be repeatedly tempered or annealed, to prevent their falling to pieces in extending their surfaces. The cohesion of the metals is of all other materials the greatest.

ALLOYS OF METALS

Are generally stronger than is indicated by the mean strength of the composition; there are, however, some exceptions. Alloys of two brittle metals, such as bismuth and tungsten, are always brittle; one part of lead and one of antimony are very brittle; bismuth and antimony make most of the alloys brittle. Two ductile metals may form a brittle alloy, as gold with copper or lead. Most of the alloys are, however, ductile; as bronze, copper and tin, copper with zinc in brass, gold and silver in coins. German silver is very strong; it is composed of copper, zinc and nickel. Some of the alloys lose their ductility in part at a higher heat, as brass, iron and copper, and pig-iron. The fusibility of alloys is generally lower than the mean of the composition, sometimes even less than the congealing point of the most fusible of the compositions. The hardness of alloys is in some cases very remarkable; a small amount of silver, one-fourth of one per cent., imparts great hardness to steel. Sixty per cent. of iron and 40 of chrome form an alloy almost as hard as diamond.

WATER

Plays an important and indispensable part in our investigations. It is the most important source of power at our disposal, either directly by its gravity, or indirectly by the high elasticity of its vapour. Water is generally transparent, inodorous, and, what renders it very valuable, almost incompressible. It is diffused through all nature; there is no material free from its admixture, except metals and vitreous compositions. Many materials, as potash and clay, have so great an affinity for water, that a red heat is not sufficient to drive off all the moisture they contain. As we find the liquid water in nature, it is more or less impregnated with vegetable, gaseous and saline matter, which give it in many cases valuable medicinal qualities, but not unfrequently impair its fitness for mechanical uses. These admixtures are derived from the rocks and ground over which the water flows. The incrustations which form in the bottom and sides of steam-boilers are caused by the precipitation of the impurities, in consequence of the concentration of the water in the boiler; they may be effectually removed, no matter what their nature, by boiling charcoal in the water. Water for the use of breweries, printworks, paper-mills, &c., should be clear and perfectly pure; if such water cannot be obtained, it must be purified by settling the mud or mechanical admixtures in reservoirs or tanks, and filtering it afterwards through charcoal, and finally through fine sand. If the water, previous to filtering, can be heated, to expel all the air and carbonic acid gas, which is frequently the solvent of the foreign matter, the filtering process will be accelerated, and will be more effectual. The process of clearing water by mere settling of the impurities is very slow, and in most cases ineffective.

If water of great purity is required, it is advisable to mix it with about 0·0001 part of alum, and filter through charcoal. Where water is very impure, as that which issues from swamps and low grounds, it should be run into flat tanks and allowed to putrefy, the more thoroughly the better; the putrefied water should then be filtered through charcoal, which will remove all the impurities, if the fermentation has been carried so far as to destroy all the animal and vegetable matter which may be contained in the water. The most fetid water may be purified by means of charcoal, if no impurities are left dissolved in it, which can well happen with stagnant water, if the vegetable matter in it was not decomposed previous to filtration.

Water is limpid to 33°, and, if not in motion, it may be cooled down to 20° or less; the least shaking motion, however, will congeal it. Water boils in the open air invariably at 212°; it is 815 times heavier than air. Rain-water is generally called soft in contradistinction to spring-water, which is considered hard. The softness, which consists in a solvent action upon the fatty substance of the skin, is owing to a small amount of carbonate of ammonia, which is formed in the atmosphere, and precipitated with the water. Rain-water is more pure than other water, and for practical purposes may be considered chemically pure. Spring or well-water, which, as we have said, is considered hard, is adulterated with basic salts in various forms, most of which may be precipitated by gently heating the water, and filtering it through charcoal. In respect to purity, river-water comes next to rain-water; it rarely contains impurities to any injurious extent. The water from mountain streams and rivulets is always purer than that from low grounds, because such water runs rapidly, and generally over gravelled beds, which expel the gas from the

water, and condense the imperfectly acidulated basic salts which it may contain. Sea-water is highly charged with impurities, its specific gravity on this account being 1·03. The action of water upon vessels and conducting pipes is frequently of a corroding character, and hence care and attention are required in laying hydrant pipes. The subject has never been thoroughly investigated. Some leading points, however, are given, which are sufficient to cover the ground as far as our interest extends. As lead and iron are generally employed in conducting water, it is unnecessary to speak of any other material. Iron is liable to corrode, or, what is worse, to precipitate and deposit impurities from the water which it is employed to convey. These deposits, which finally fill the pipes and interrupt the current, are mostly caused by waters which issue from springs, low marshy grounds, wells, alluvial deposits, or the vicinity of rocks of gypsum and limestone. Water which has its source in granite, gneiss, porphyry or metamorphic rock, sandstone, or in dry sandy valleys, never attacks iron, or causes deposits in the pipes. Rain and soft river-water are equally free from injurious sediment. Leaden pipes are more liable to corrosion than those of iron; and, as a solution of lead in water is injurious to health, it requires a twofold attention and a close investigation into the nature and chemical composition of the water to be conducted. We may decide as to the propriety of employing lead by referring to the solvent powers of water on the oxides and salts of lead. All these salts are more or less soluble in water, with the exception of the sulphate of lead; and even this is in some measure soluble if the water contains chlorides or free muriatic acid. There is no security against the solvent power of water on lead, particularly if the water should contain air, or if air is

accessible to its current while in motion. All water, rain not excepted, will dissolve more or less lead; the quantity is frequently very minute, but it may be detected by chemical re-agents. The safest way to avoid unwholesome influences upon men and animals is not to use leaden pipes where a great length, say more than one hundred feet, is required. There will be no danger in short conductors; and leaden pipes of fifty feet long, in which it is designed to conduct rain or river-water, need give rise to no apprehension, though they are of doubtful propriety with some spring water. It is from well, spring, brackish and swamp water that the danger chiefly arises.

Wooden pipes are in doubtful cases preferable to either iron or lead, so far as health is concerned, but are very imperfect in respect to durability and convenience. They are liable to be filled with weeds, which often grow rapidly, and, if once rooted, are of difficult extermination. Wooden pipes will not bear much pressure, and are liable to incessant leakage. Earthenware, stoneware, and glass pipes are the most safe in respect to health, and, where the pressure to be sustained by the pipe is not beyond its strength, they are the least troublesome, and remove all difficulties of a sanatory character. A well-made stone-ware pipe of four inches diameter will bear from seventy-five to one hundred pounds of pressure to the square inch.

ATMOSPHERIC AIR

Is a very important element, not only to the well-being of all organized creation, but as a source of power. Steam has in some measure superseded the application of air as a motor; but there is still enough left to interest and attract our attention. The navigation of the ocean, which has been pursued since the dawn of maritime industry, is still

carried on by the help of air; and centuries must elapse ere the sailing-vessel becomes a memory of the past. In common life, the bellows which fans the kitchen, parlour, and factory fire, is still moved by the passage of air in a chimney. And it is almost a source of regret that the poetical wind-mills have lost so much of the attention they formerly engrossed, by the introduction of steam-power. Atmospheric air is undoubtedly the cheapest and most extensive of all sources of power; and nothing but its diluted form has been the cause of steam gaining the ascendency over it. The bulk of air required to produce a certain quantity of motion is comparatively too large, and the means of transmission are too awkward to suit our present ideas of perfect machinery.

Another obstacle in the way of the application of atmospheric air as a motive power is its irregularity, sometimes coming in a strong gale, and at other times in a gentle breeze, which obviously unfits it as a motor for factories. The difficulty might indeed be overcome if we could concentrate and transfer the power from one machine to another; but this is, as yet, impracticable.

The most remarkable quality of atmospheric air, and that in which we are most interested, is its capacity of dissolving, or rather mingling with the vapours of water. The evaporation of oceans, seas, lakes, rivers, canals, &c., is universal, and is of the greatest importance to the welfare of mankind. Without it, the earth would become a vast desert, and aridity and desolation would characterize her most fertile spots. The capacity of atmospheric air for water is very great, and is increased by motion and temperature; and as the laws regulating the formation of gases are everywhere the same, and as, in addition, evaporation forms a very important source of motion, too much atten-

tion cannot be bestowed upon it. The incumbent atmosphere is a serious obstacle to evaporation, if it is filled with the vapours of the liquid itself to be evaporated. In a vacuum, therefore, evaporation goes on most rapidly, no matter of what description the liquid may be. Next to a vacuum in the rapidity of its action, is an atmosphere of those gases to which the liquid or its vapours have the most affinity. In practice, we can scarcely find anything which has more affinity for the vapours of water than the atmospheric air, when that air is in motion. The amount of vapour in the atmosphere varies from one-half to four per cent. in bulk, the quantity being from 6·1 to 10·18 by measurement. The quantity is smaller in the forenoon, or before two o'clock, and larger from that period to sundown. The higher the temperature of the atmosphere, the greater is the absolute quantity of vapour. It is also greater in summer than in winter, in day than in night time, in low countries than in high, and in warm than in cold climates. The proximity of seas, lakes and rivers, increases the vapours in the atmosphere; while dry or barren land diminishes the amount of moisture. A luxurious vegetation is therefore favourable, and a want of verdure is detrimental to it. One cubic inch of air weighs 31·01 grains; at a temperature of 62°, it is 815 times lighter than water, and at 32° it is 770 times lighter than that element. The height of the atmosphere, if it were of equal density, would be 5·238 miles. If the atmosphere is permitted to press upon a vacuum, it will press with all its weight; that is, a vertical column of five miles high, and a base equal to the surface of the vacuum, which is equal to fifteen pounds upon the square inch, thirty inches high of mercury, or a column of water thirty-four feet in height. The height of these columns of water, mercury, &c., is variable, as it is influ-

enced by the commotion of the air, the amount of watery vapour which it may contain, and by various other causes. As is the case with all other gases, air expands its bulk for each ascending degree of the thermometer $\frac{1}{175}$ part. The expansion caused by heat is the moving power which keeps our fires alive, by producing a constant current of fresh air through the hot coal.

CHAPTER II.

MATHEMATICAL LAWS.—PROPERTIES OF NUMBERS AND SPACE.

NUMBERS.

If a number consists of many parts, and each of those parts has a common divisor, then the whole number, taken collectively, will be divisible by that divisor.

If a square number be either multiplied or divided by a square, the product or quotient is a square; and if a square number be either multiplied or divided by a number that is not a square, the product or quotient is not a square. The product arising from two different prime numbers cannot be a square number.

The square root of an integer number, that is not a complete square, can neither be expressed by an integer nor by any rational fraction. The cube root of an integer, that is not a complete cube, cannot be expressed by either an integer or a rational fraction.

No algebraic formula can contain prime numbers only. A square number cannot terminate with an odd number of

ciphers. If a square number terminates with 4, the last number but one towards the right will be an even number. If a square number terminates with 5, the last number will terminate with 25. If a square number terminates with an odd digit, the last figure but one will be even; and if it terminates with an even digit, except 4, the last figure but one will be odd. No square number can terminate with two equal digits, except two 0's and two 4's. No number whose last or right-hand digit is 2, 3, 7 or 8, is a square number.

If a cube number be divisible by 7, it is also divisible by the cube of 7. The difference between any integral cube and its root is always divisible by 6. Neither the sum nor the difference of two cubes can be a cube. A cube number may end with any of the natural numbers. If a series of numbers, beginning with 1, be in continued geometrical progression, the 3, 5, 7, &c., will be squares; the 4, 7, 10, &c., will be cubes. If unity be divided into any two unequal parts, the sum of one of these parts, added to the square of the other, is equal to the sum of the other part, added to its square.

EQUATIONS

Consist generally of known and unknown quantities. The reduction of an equation consists in managing its terms so that, in the end, the unknown quantity is disengaged from the known quantities, by performing upon both members the same reverse operation. Thus, if any known quantity be added to the unknown quantity, let it be subtracted from both members or sides of the equation; and if any known quantity be subtracted, let it be added. If the unknown quantity have a multiplier, divide the equation by it, and if the unknown is divided by any quantity,

let that quantity be the multiplier. If any power of the unknown quantity be given, take the corresponding root; and if any root be given, take the corresponding power. If the unknown quantity be found in the terms of a proportion — that is, equality of difference, or equi-difference, and equality of ratios — let the respective products of the means and extremes constitute an equation, and then apply the general principle.

When two unknown quantities are to be determined from two independent equations, it is advisable to find one of the unknown, in each of the given equations; make those two values equal to one another in a third equation, and from thence deduce the unknown. This, substituted for either of the former equations, will lead to the determination of the first unknown quantity. Or, find the value of either of the unknown quantities in one of the equations, and substitute this value in the other equation. The most practical rule, however, is to multiply, after due reduction, the first equation by the coefficient of one of the unknown quantities in the second equation, and the second equation by the coefficient of the same unknown quantity in the first equation. The addition of the resulting equations, with the necessary subtraction, will lead to the extermination of that unknown quantity, and determine the other by former rules.

QUADRATIC EQUATIONS.

A simple rule for the solution of quadratic equations is Hutton's rule of "trial and error," given in Gregory's Mathematics. Find, by trial, two numbers as near the true root as possible, and substitute them in the given equation instead of the unknown quantity, marking the errors which arise from them. Multiply the difference of

the two numbers, found by trial, by the least error, and divide the product by the difference of the errors when they are alike, but of their sum when they are unlike. Add the quotient last found to the number belonging to the least error, when that number is too little, but subtract it when too great, and the result will give nearly the true root. Take this root, and the nearest of the two former, or any other that may be found nearer, and, by proceeding in like manner, a root will be had still nearer than before. This can be continued to any degree of exactness.

The root of the equation $x^3 + x^2 + x = 100$, will easily be found to be between 4 and 5; the operation is then as follows:

Suppose 4.		Suppose 5.
4	x	5
16	x^2	25
64	x^3	125
84	sums.	155
— 100		— 100
— 16	errors.	+ 55

The sum of 16 and 55 is 71. Here is

$$71 : 1 :: 16 : \cdot 225,$$

or $x = 4 \cdot 225$ nearly.

Suppose		
4·2	x	4·3
17·64	x^2	18·49
74·088	x^3	79·507
95·928	sums.	02·297
— 100		— 100
— 4·072	errors.	+ 2·297

The sum of which is 6·369.

6·369 : 1 : : 2·297 : ·036
taken from 4·300
x nearly = 4·264

INVOLUTION,

Or the rising of powers, is so safe and simple an opera tion, that it is not necessary to allude to it particularly.

EVOLUTIONS

May be forgotten; and for this reason we will add the extraction of roots in its practical operations. The square root is found by dividing the number into periods of two from the right, and setting a point over the place of units, another over the place of hundreds, and in like manner over every second figure; to the left in the integers, and to the right in the decimals. After that, find the greatest square in the first period to the left, and set its root to the right of the given number. Subtract the square thus found from the first period, and to the remainder annex the two figures of the next following period for a dividend. Double the first root for a divisor, and find how often it is contained in the said dividend, exclusive of its right-hand figure, and set that quotient figure both in the quotient and divisor. Multiply the whole augmented divisor by this last quotient figure, and subtract the product from the said dividend, bringing down the next period of the given number for a new dividend. Repeat this process; that is, find a new divisor by doubling all the figures now found in the root; from this, and the last dividend, find the next figure of the root as before, and so on to the end.

A good way of doubling the root to form new divisors.

is by adding the last figure always to the last divisor. After the given figures are exhausted, the operation may may be continued at pleasure.

Example.

The square root of $\dot{1}\dot{7}\cdot\dot{3}\dot{0}\dot{5}\dot{6}$ (is 4·16 the root.

16	
81	130
1	$81 = 81 \times 1$
82	4956
6	$4956 = 826 \times 6.$
826	

CUBE ROOT.

To find the cube root, it is best in practice to extract by approximating rules, instead of by logarithms; though, if logarithmic tables are at hand, it may be more convenient to resort to them.

By trials or experiment, take the nearest rational cube to the given number, whether it be greater or less, and call it the assumed cube. After this, take the sum of the given number, and add to it double the sum of the assumed cube; this sum is to the sum of the assumed cube and double the given number, as is the root of the assumed cube to the root required. This process can be repeated until a cube is found as nearly correct as is required for specific practical purposes; using always the cube of the last found root for the assumed cube.

To find the cube root of 21035·8.

The root is here more than 27 and less than 28. Taking 27, the cube of which is 19683 the assumed, 21035·8 the given number,

19683		21035·8	
2		2	
39366		42071·6	
21035·8		19683	
60401·8	:	61754·6	:: 27 : 27·6047.

Here we have 27·6047 nearly true: it may be made still more correct by repeating the process.

PROGRESSIONS.

An arithmetical progression is where the qualities proceed in equi-differences.

An ascending arithmetical progression is 1, 3, 5, 7, 9, and so on.

A descending arithmetical progression is 12, 10, 8, 6, 4, &c.

If the numbers proceed in the same continual proportion, or by equal multiplications or divisions, they form "geometrical" progressions.

An ascending geometrical progression is 1, 3, 9, 27, 81, &c.

A descending geometrical progression is 6, 3, $1\frac{1}{2}$, $\frac{3}{4}$, $\frac{3}{8}$, &c.

COMPUTATION OF FORMULÆ.

One of the most important operations in practice is the "computation of formulæ," which, amongst all algebraic and arithmetical operations, is soonest forgotten. The facility to calculate is one of the most characteristic qualities of the practical mathematician; it will, however, soon be lost for want of practice.

If $g = 32\frac{1}{2}$, and $t = 6$, what is the value of $\frac{1}{2}g \times t^2$?

$$\frac{1}{2}g \times t^2 = \frac{32\frac{1}{2}}{2} \times 6^2 = 96\frac{1}{4} \times 6 = 579.$$

If $a = 1$, $h = 25$, $g = 193$, what is the value of $2 \times a \times \sqrt{g \times h}$?

$$2 \times a \times \sqrt{g \times h} = 2 \times \sqrt{25 \times 193} = 10 \times \sqrt{193} = 10 \times 13{\cdot}892 = 138{\cdot}92.$$

If $f = \frac{\pi \cdot 11^2}{4}$, $k = 7400 \times \frac{4}{5}$, what is $\frac{f \times k}{10}$?

$$f \times k = \frac{3{\cdot}1415 \times 11^2}{4} \times 6200 = 95 \times 6200 = 58900.$$

SPACES.

A surface has only length and breadth. The extremes or limits of a surface are lines. A plane lies perfectly even between its extremes. A solid extends every way, has length, breadth and depth, and its extremes are surfaces. In any triangle, the sum of the three angles is equal to two right-angles. The angles at the base of an isosceles triangle are equal. In any triangle, the greatest side is opposite to the greatest angle. The sum of two sides of a triangle is always greater than the third side. If two triangles have all their sides equal, all the angles will be equal, and the whole equal. If two triangles have two sides in each and the included angle equal, these triangles and their corresponding parts are equal. If two triangles have two angles each and one side equal, the whole of the triangles will be equal. Triangles of equal bases and equal height have equal contents. The contents of equally high triangles are in proportion to the length of their bases. All the lines drawn parallel with one side of a triangle, are proportional to the distance from that side If a perpendicular is drawn upon the hypothenuse of a right-angled triangle, from the right angle, it will divide

the triangle into two similar triangles, which are similar to the whole. The distance of the right angle from the middle of the hypothenuse is equal to half the hypothenuse. In a right-angled triangle, the square of the hypothenuse is equal to the sum of the squares of the two sides. If an angle be bisected by a right line, which cuts the base, the segments of the base will be proportioned to the adjoining sides of the triangle. Three lines drawn from the three angles of a triangle to the middle of the opposite sides, all meet in one point, and this point will be equidistant from the three angles; it will also be the centre of a circle drawn through the angles. Three perpendiculars, drawn from the three angles of a triangle to their respective sides, all meet in one point. Three lines bisecting the three angles of a triangle, also, meet in one point.

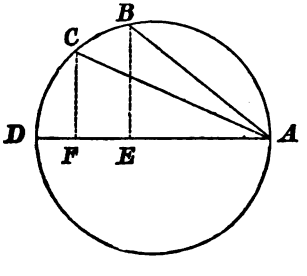
In any parallelogram, the opposite sides and angles are equal, and a diagonal divides it into two halves, or equal triangles. The diagonals of a parallelogram intersect each other in the middle. Any line passing through the middle of a diagonal of a parallelogram, divides the area into two equal parts. In any parallelogram, the complements on each side of the diagonal are equal. Parallelograms of equal bases and height are equal. Parallelograms of the same height are to one another as their bases, and those of equal bases are as their height. In a parallelogram, the sum of the squares of the diagonals is equal to the sum of the squares of all the four sides.

The sum of the four internal angles of any quadrilateral figure is equal to four right angles. The sum of all the angles of a polygon is equal to twice as many right angles, less four, as the polygon has sides. The sum of the external angles of a polygon is equal to four right angles.

Only three sorts of regular figures can fill up a plane surface; that is, a whole space round an assumed point; these are six triangles, four squares, and three hexagons.

All the radii and diameters of a circle are equal. If a line bisects a chord at right angles, it passes through the centre of a circle. A radius that bisects the chord also bisects the arc. In a circle, equal chords are equally distant from the centre. The greatest line in a circle is the diameter. No circle can cut another in more than two points. In any circle, the arcs and sectors which are formed by equal angles of several radii are equal. The circumferences of circles are to one another as their diameters or radii. In a circle, the angle at the centre is double that at the circumference, standing upon the same arc. The tangent touches the diameter perpendicularly at the point of contact with the periphery. A tangent to the middle point of an arc is parallel to its chord. In a circle, fig. 2, if the diameter A D be drawn, and from the ends of the chords A B, A C, perpendiculars be drawn upon the diameter, the squares of the chords will be in proportion to the segments of the diameter. If from a point exterior to a circle two tangents be drawn, they will be equal. A circle is equal in area to a triangle whose base is the circumference of the circle, and whose height is the radius. Circles are to one another as the squares of their diameters, or as the squares of the radii, or the squares of the circumference.

Fig. 2.



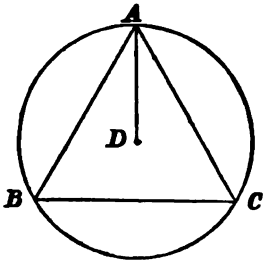
If an equilateral triangle, A B C, fig. 3, be inscribed in

a circle, the square of the side thereof is equal to three times the square of the radius.

$$AB^2 = 3\,AD^2.$$

A square inscribed in a circle is equal to twice the square of the radius.

Fig. 3.



BODIES.

If a cylinder be cut in a plane parallel to its base, the section will be a circle equal to the base. If any prism be cut by a plane parallel to its base, the section will be equal, and like the base. Similar prisms and cylinders are to each other as the cubes of their altitudes, or of any like their linear dimensions. In any pyramid, a section parallel to the base is similar to the base; and these two planes are to each other as the squares of their distances from the vertex.

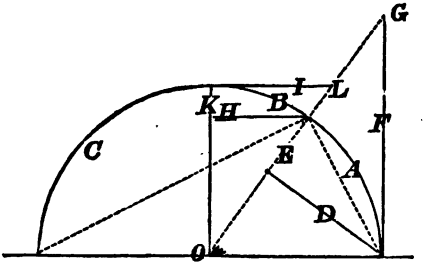
In a cone, any section which is parallel to the base is a circle; and this section is to the base as the squares of their distances from the vertex. All pyramids and cones, of equal bases and altitude, are equal to one another. Every pyramid is a third part of a prism of the same base and altitude. Every sphere is two-thirds of its circumscribing cylinder. All spheres are to each other as the cubes of their diameters. The sphere is the greatest and most capacious of all bodies of equal surface.

ANGLES.

The circumference of a circle is 360° (degrees); each degree 60′ (minutes); and each minute 60″ (seconds). A

right angle and a quadrant are each 90°. The complement of an arc is its difference from the quadrant, and the complement of an angle is its difference from the right angle. The supplement of an arc is its difference from a semicircle, and the supplement of an angle is its difference from two right angles. The sine of an arc is a perpendicular let fall from one extremity upon a diameter passing through the other extremity. The versed sine of an arc is that part of the diameter which is intercepted between the foot of the sine and the arc. The tangent of an arc is limited by a right line drawn from the centre of the circle through that extremity of the arc which does not touch the tangent. The secant of an arc is that line which thus limits the length of the tangent. These terms may be used either for the angle or the arc belonging to it. The cosine of an arc or angle, is the sine of the complement of that arc or angle. The cotangent is the tangent of the complement of that arc or angle. The co-versed sine is that versed sine which belongs to the complement of that arc or angle. The co-secant is the secant belonging to the

Fig. 4.



complement of an arc or angle. In fig. 4, B is the complement of A, C is the supplement of A, D is the sine of

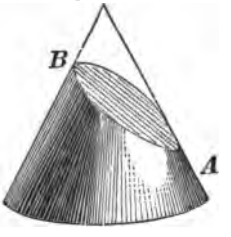
A, E is the versed sine of A, F is the tangent and G O the secant of A; H is the cosine, I the cotangent, K the co versed sine, and O L the co-secant of A.

CONIC SECTIONS

Are most useful mathematical constructions, and deserve careful attention. There are five conic sections; but the circle and triangle do not interest us. The other three — the ellipsis, hyperbola and parabola — are of general application. The ellipse is formed in cutting a cone obliquely through both sides, or in a less angle than the sides of the cone. A parabola is formed when a cone is cut parallel with the side; and a hyperbola, when the cutting plane forms a greater angle with the base than the sides.

THE ELLIPSE,

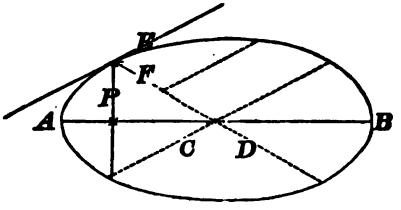
Fig. 5.



As shown in the annexed figure, (5,) has two vertices, A B; these are the points where the cutting plane meets the opposite sides of the cone. A B is the major axis, or transverse diameter. The centre is in the middle of this axis; the axis and centre are therefore within the curve. A diameter is any right line drawn through the centre, and terminated by the curve; the extremities of the diameter are its vertices. A conjugate, C, fig. 6, is parallel to the tangent E, belonging to the diameter D. The conjugate to the axis A B is the minor axis. An ordinate is parallel with the conjugate, and is terminated by the diameter to which it belongs, and by the curve. All the ordinates to the axis are perpendicular to it, but not to any other diameter. An

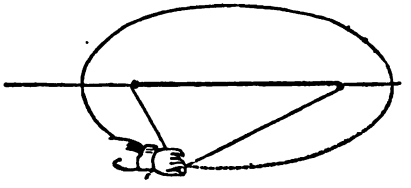
abscissa, F, is that part of the diameter between an ordinate and the vertex of the diameter. The focus is a point in the axis where it is cut by the parameter, P.

Fig. 6.



An ellipse is easily constructed, where the two axes are given, by multiplying the major axis by itself, and subtracting the square of the minor axis from this sum; the remainder is the distance between the two foci. In the two foci, fig. 7, fasten two pins or needles, and then take a

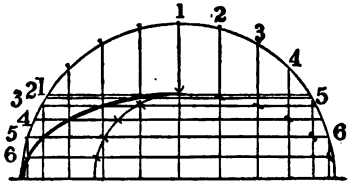
Fig. 7.



fine strong thread, or a fine hair wire, and make it as long as the major axis, plus the distance between the foci; join the two ends, and lay it around the pins. By putting a pencil in the long, or loose side of the wire, and moving it round in the string, a correct ellipse will be drawn. Another method, sufficiently accurate for practical purposes,

if the foregoing cannot be applied, is to draw a circle which has the given major axis for a diameter, fig. 8; divide the circumference into equal parts, and draw from these points of division perpendiculars upon the diameter, or, what is the same, join opposite points; divide now the circle of the minor axis into the same number of parts as the circumference of the large circle, and draw from these points lines parallel with the major axis. Where these latter lines and the perpendiculars cut one another, the points are to be joined by hand, to form the ellipsis. The smaller the

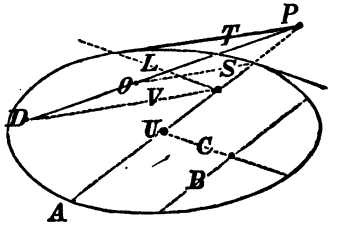
Fig. 8.



divisions, the more correct will be the ellipse. This method is very convenient in forming small figures; it is not, however, a correct ellipsis.

A tangent to a given point out of the ellipse can be arrived at if we draw from that point a line to the centre, and parallel with that line, which prolonged will form a diameter; a chord, fig. 9, B; divide that chord, and connect the centre of the diameter with the middle of the chord; the line C will be the conjugate to the diameter. Draw DP = PA,

Fig. 9.



and PO = DU; then draw S, and V parallel to S; where V cuts the diameter, draw a line L parallel to C; where L cuts the curve, is the point where the tangent joins the periphery. The tangent of the major axis is parallel to it.

THE PARABOLA,

Fig. 10, has but one vertex, and its axis is indefinite in length; the centre of the parabola is also of infinite distance from the vertice. All the diameters of the parabola are parallel with the axis, and indefinite in length. The parabola has but one absciss; the other vertex of the diameter is indefinitely long. The parabola has also but one focus. A parabola may be constructed in a simple manner by drawing a triangle, or the sides of a pyramid, whose base is equal to the proposed parabola, and its height twice

Fig. 10.

Fig. 11.

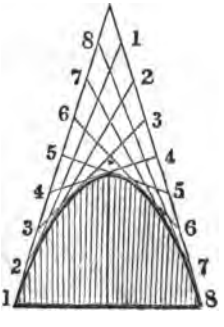
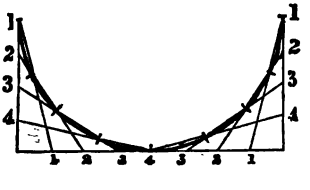


Fig. 12.

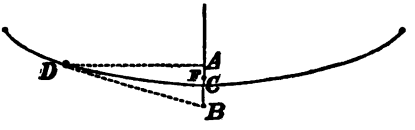


as great (fig. 11). Divide the sides into equal parts, and connect the corresponding upper and lower divisions of the

opposite sides. The points where these lines cut the parabolic line are to be joined, to form the parabolic curve; these lines are in the direction of the tangents. A more convenient method, in many instances, is the following:— If, as in fig. 12, the length is different from the height of the parabola, form a rectangle of the two dimensions, divide the axis into half as many parts as the base, and connect the corresponding parts. The points where the lines connected cut one another, form the parabolic curve.

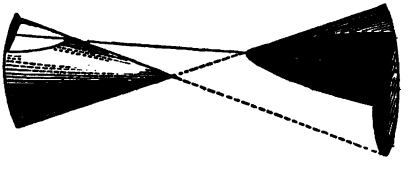
To draw a tangent to a parabola from a certain point in the curve D, is simply done, if we draw from that point an ordinate upon the diameter. Where this ordinate cuts the axis in A, fig. 13, prolong the axis to B, so that BC=AC, and then join B with the given point D, which line will be

Fig. 13.



the tangent. Joints in arch-stones are to be perpendicular upon the tangent. The focus F for the parabola ACD is one quarter of the parameter C towards A.

Fig. 14.



THE HYPERBOLA.

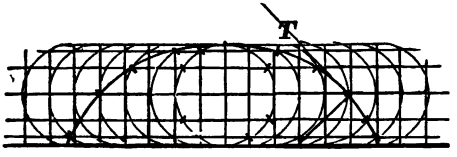
The opposite hyperbola, fig. 14, has two vertices, and every diameter of the hyperbola has two vertices. Every ordinate has two abscisses. The focus of the ellipse, the parabola, and the hyperbola, is in that point of the axis, where the ordinate is equal to half the parameter.

CURVES.

THE CYCLOID

Is a curved line, described by any point in the circumference of a wheel running in a straight line. The nail in the tire of a carriage-wheel describes a cycloid at each revolution. The line upon which the generating circle revolves is the base line of the cycloid. The diameter of the generating circle is the axis of the cycloid in that point where it meets the curve in the vertex. A cycloid can be drawn directly by describing it with the point of a pencil fastened in the periphery of any circular plane, and rolling it in a straight line. This may be done more conveniently, and with almost equal correctness, by dividing a straight line, of the length of the circumference of the given circle, (fig. 15,) into equal parts, and the circumference of the

Fig. 15.



circle into the same number of parts, drawing parallel lines through the dividing points of the circle, and erecting per-

pendiculars upon the dividing points in the base line. From the point where the perpendiculars cut a parallel drawn through the centre of the generating circle, draw a succession of circles; and where these circles cut the parallels to the base, are the true joints, which, being connected, form the cycloid. The cycloid is the true form of the curve of cogs in a straight rack. Other forms, such as the curtate and prolate cycloid, have little bearing in our investigations. The cycloid is a very important curve in pendular vibrations, because, if the point of gyration in a pendulum moves in the curve of a cycloid, the pendulum will perform its vibrations in equal times. The tangent of a cycloid is found in drawing a chord from the point of contact in the generating circle and the base line, to the opposite point of contact of the generating circle and the curve; in prolonging this chord, it will form the perpendicular to the tangent T in fig. 15. The length of the cycloid is equal to four times the diameter of the generating circle. The area enclosed by the cycloid and its base line is equal to three times the area of the generating circle.

The *Evolute* is a cycloid cut at the vertex, and joined in both ends at the base. The evolute forms the curvature for the driving cogs of a rack.

THE EPICYCLOID

Is the true curve of the cogs in two wheels. It is based upon the principle that a point in the periphery in one of two circles which is assumed to be in motion, will describe a particular curve when that circle is rolled around the other in the same plane. The curve described is the epicycloid, belonging to the circle which forms the base. The construction of an epicycloid is shown in fig. 16. The

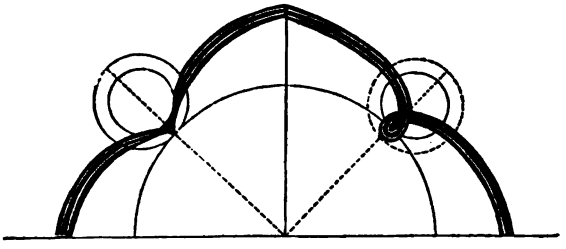
Fig. 16.

larger circle may represent the larger wheel; it forms the base line to the epicycloid described by the small circle. The small circle is divided into equal parts, and through these divisions large circles are drawn. The base line, or part of the circumference of the large circle, is divided into the same number of equal parts as the small circle, and through these points radii are drawn. Where these radii cut the large circle, drawn through the centre of the small circle, are the centres for the generating circles. Where the generating circles cut the large circles, there are the true points, which, when connected, will form the epicycloid. Essentially, the construction of the epicycloid is the same as that of the cycloid, with the difference of a curved base line. In reversing the operation, that is, taking the small circle for the base line, we construct the epicycloid for the small circle. The tangent to the epicycloid is easily found in the same way as that to the cycloid, if we remember that the base line is one of the circles, and that the chord is to be drawn from the point where the radius cuts the generating circle, to the opposite point, where the generating circle cuts the ascending curve. The evolute to an epicycloid may be very readily drawn.

In varying the describing points of the generating circle, that is, making the describing circle larger or smaller than the rolling circle, a succession of very graceful and interesting curves may be drawn. This is illustrated in fig. 17, where, on one side, the describing point is removed

from the centre of the generating circle, and in the other towards the centre.

Fig. 17.



THE HYPOCYCLOID

Is constructed on the same principle as the cycloid or epicycloid, with the difference that the generating circle rolls inside of the base circle. The construction of this curve will be easily understood, and requires no particular illustration. The hypocycloid is a straight line, or forms the diameter of the larger circle, if the smaller circle is half the size of the larger.

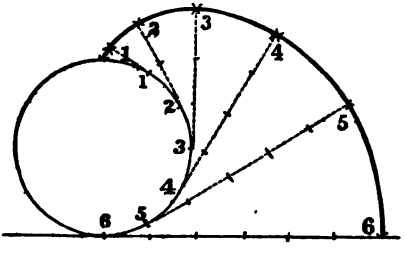
The number of curves described by rolling circles one upon the other, inside or outside — a circle upon a sphere, or a sphere upon a circle — the rolling of a circle upon curves, or curved planes — may be made infinite by altering the elements of generation. All of the curves generated in this way are graceful; and on this account the cycloid and its derivatives deserve particular attention. They are also very useful and important curves for the mechanic. The cycloid is the curve of swiftest descent, and consequently of the least friction; and all its derivatives are of the same character. These lines are of less importance to the formation and correct construction of cog-wheels, than they are in the construction of floating

vessels, and in hydro-dynamics generally. It would take too much space to examine this subject thoroughly; but we shall refer to it again in another place.

THE EVOLVENT

Is a line which is formed by developing the circumference of a circle, as if we wind a thin, stiff thread upon a circle, and in unwinding it, provided the circle is at rest, describe with the end of the thread a curved line. The body around which the thread is wound must not necessarily be a circle; it may be of any other form. The evolvent of a straight line will be a circle; the evolvent of a circle may be infinite, as a spiral. The construction of an

Fig. 18.

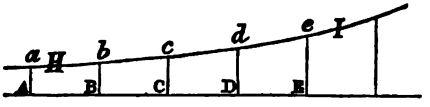


evolvent is shown in fig. 18, and explains itself. If the circle is replaced by an ellipsis, and the thread wound around more than once, a waved curve will be formed.

THE LOGARITHMIC LINE

Is found where the ordinates form a geometrical progression, and the abscisses form an arithmetical progression. If, in fig. 19, AB, AC, AD, are in an arithmetical progression on the base line AE, or on the diameter of any

Fig. 19.

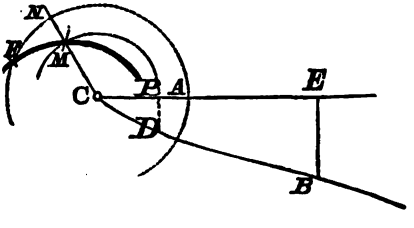


figure; and are A*a*, B*b*, C*c*, &c., in a geometrical progression; then the line HI will be the logarithmic line. We find here, by assuming A*a*=I, that the abscisses are as the logarithms of the corresponding ordinates. To construct a logarithmic line is not difficult, if we divide the axis of the abscisses, and erect upon the division points the corresponding ordinates, which may be of either given or assumed lengths, provided they progress in a geometrical ratio. The tangent, sub-tangent, radius, arc, &c., of a logarithmic line, are problems not in direct correspondence with our subject.

THE SPIRAL

Is a curve which is formed in a more complicated way than any other. If, in fig. 20, PC and PD are two co-or-

Fig. 20.



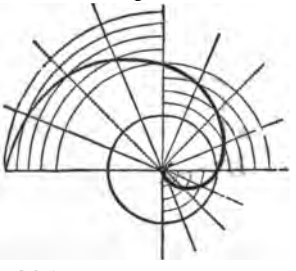
dinates, CE and EB two others, forming the line BD, which may be either curved or straight, and the line EC, which also may be either curved or straight; then from the cen-

tre, C, describe the circle AF, with a radius = 1, or the unity. The arc AN is to be a part belonging to one of the ordinates, either PD or EB. If now the abscissa, belonging to the ordinate used say PC, is laid in the radius from N to M, we have formed one point in the spiral to be constructed. The other points in question are found in a similar manner. The line BD is the generating line, C the pole or centrum, and CM the radius vector of the spiral curve. If the generating line is a straight line, parabola, or hyperbola, the spiral will have a corresponding name.

THE SPIRAL OF ARCHIMEDES

Is a curve where the generating line is straight. Where the axis of the spiral, passing through the centre of it, is cut in some place more or less distant from the centre, the spiral will in consequence assume a more or less circular form. Where the centre of the axis and the generating line fall together, the progressing angles and the distances from the centre are in proportion. If the number of revolutions of a spiral, or the distance between each revolution, are given, and the axis and the generating line fall together, the construction of a spiral is very simple. So also if the axis is a circle, as in fig. 21. The figure requires but little explanation. The ordinate is here the angle or arc belonging to it, and the abscissa is the distance from one circle to the other. Where the radius and circles cut one another, there are given points which, if connected, form the spiral.

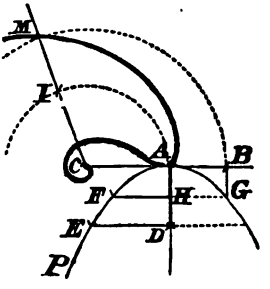
Fig. 21.



THE PARABOLIC SPIRAL

Is formed when the generating line is a parabola. The form of the spiral depends upon the form of the parabola. In fig. 22, make CB the axis of the spiral, which touches the generating parabola P in its vertex; AD one of the given co-ordinates, and DE the other; GH and HF are also co-ordinates. In drawing the arc BM, which is to be proportional to the ordinate GH, and IM to the abscissa AH; the interior part of the spiral AC vanishes entirely if the vertex of the parabola falls together with C.

Fig. 22



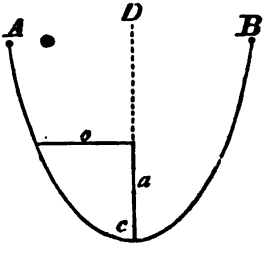
THE HYPERBOLIC SPIRAL

Is constructed in a similar manner as the parabolic; an hyperbolic curve forming the generating line. By substituting a logarithmic, or in fact any other line, we may, in constructing on the same principle, form an infinite number of spirals.

THE CATENARY

Is that curve which is assumed by a chain, or a perfectly flexible cord, of uniform substance and size. If a line of such material is suspended on its two ends, it assumes the form of a catenary, or the line of equilibrium in arches and suspension chains, or cables. If, in fig. 23, AB are points of suspension, then C is the vertex, and CD the

Fig. 23.

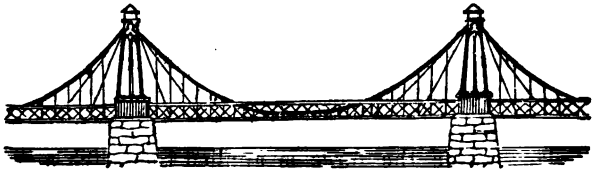


parameter. The chief characteristics of the catenary are, that the horizontal tension is equally great at all points; the vertical tension is equivalent to the vertical tension at the points of suspension; and the vertical tension at the vertex is null, since it is all converted into horizontal tension. The tension at one of the points of suspension is equivalent to the weight of the chain from that point to the vertex. In the common catenary — that is, the simple line — there are equal arcs of equal weight; it is therefore not very difficult to find the weight as well as the length of any part of the catenary to its abscissa, provided the length of the chain is known, and its weight per foot. The common catenary is, however, of very little use in practice; we have to deal here with catenaries which are more or less modified, on account of the weight which they carry.

SUSPENSION BRIDGE.

When the ordinate O is very nearly equal to a, the abscissa, the catenary assumes the form of the parabola; this is frequently the case in suspension bridges, where the horizontal is converted into vertical tension. From this it is evident that the curve of the suspension bridge is a modification of the catenary, even when at rest, or under uniform pressure. If the pressure is not uniform, or more in one point than in another, the form of the catenary will be modified, and the strength of the bridge impaired, in proportion as the bridge suffers a modification of its original suspension curve. The tension of the suspended chain increases with the abscissa; if, therefore, a weight be rolled over a suspension bridge, (fig. 24), each of the suspenders will alternately draw the curve from its original form, and assume in the point of pressure a deviation, more or less resembling the parabola, or any other curve. The calcu

Fig. 24.



tions laid down for constructing a suspension bridge must therefore be modified according to the constant pressure, and the stability of the structure. The true practical line is a logarithmic line, formed by the elements given in the vertical tension of the suspenders and the cable; and these are converted partly into horizontal tension. The influence of pressure upon the catenary curve can be easily shown by suspending a soft copper wire on two points, and then fastening strings with equal weights, at equal distances, in the form of suspenders on a bridge. These weights would draw the former catenary which the wire formed by itself, into a parabola, if the wire itself had no weight. If the weights are not equal, and are more at both ends, the form of the curve will be inclined to an ellipsis. If the inflexible bridge is built on good and correct principles, it does not follow that the bridge, if elastic — that is, if its form is altered by accidental pressure — is equally good. An inflexible bridge may be very strong, and still the practical bridge — the elastic bridge — cannot resist the destroying influence of motion. In a suspension bridge, all the vertical tensions, or forces, are united at the points or extremities, and equivalent to the sum of the suspended weights. The horizontal tension is in an inverse ratio to the depression or parameter, and ought to be equal in all points of the curve.

The subject of suspension bridges may be more correctly

understood by referring to the principles of the equilibrium in funicular forces. A string or chain suspended on two points, and a force or weight applied at one part of the string, between the two fixed points, with an intention to bend or stretch it, in case it is limber, is funicular force The place where the force is applied to stretch a string, between the two fixed points, as a suspender on a wire bridge, is called a *node*. To preserve equilibrium in the forces, the one must be equal to the two which are exerted to move it from its place, in case there is motion. The resisting power is equal to the tension of the string. If the force applied between two fixed points be movable, as a wagon on a bridge, the node will be found to be in the curve of an ellipse, to which the two fixed points form the foci. In composing a number of single cases of the funicular equilibrium, we generate the funicular polygon; from such a polygon, the forces which act on a suspension bridge are computed. The curve of the suspended chain, with stiff, long links, is a funicular polygon. The curve of a wire cable is less so in form, but is the same in principle. The points where the suspenders are fastened, are the nodes; and the more fluid line of the wire cable, in contradistinction to the long linked chain, is owing to its weight and flexibility.

The formula for calculating the strength of cables, or horizontal tension, vertical tension, &c., of a suspension bridge, is comprised in the following: If we take twice the deflection of the chain in feet, and divide this by half the span, it will be the tangent to the angle of suspension on both ends. The vertical tension on each point of suspension is half the weight of the whole bridge, including the weight to be put upon it. The horizontal tension on the chains is equal to half the weight, or the vertical tension

in one point of suspension, times the cotangent to the angle of suspension. The whole tension on one point of suspension is equal to $F = \sqrt{W^2 + T^2}$; wherein W is the vertical tension in one point of suspension, and T the whole horizontal tension.

FLEXIBILITY OF ELASTIC LINES.

If a beam of any material is exposed to a force which will tend to bend it, the force applied will finally break the beam, if sufficiently strong. If a mathematical beam, say a flexible line, is fastened on one end, and weight applied to the other end, the line will be bent as much as if the beam were supported on both ends, and twice the weight distributed over its whole length. In a beam supported on both ends, and a weight suspended at a point between the supporters, the deflection is greatest if the weight is in the middle of the beam. If the weight is not in the middle, the deflection is greatest between the force and the farthest support. If the weight, depressing a beam which is supported on both ends, is distributed over the whole length, instead of being concentrated in one point, the deflection of the beam will be but five-eighths as great as in the latter case; that is, a beam will carry three-eighths more for the same amount of deflection. The angle of deflection in the centre of a beam is but half as large, if the depressing force is distributed over the whole beam, as if that force is concentrated in one point. The height of the arc, or amount of the deflection, increases as the cube of the length of the beam.

MATERIAL BEAMS

Are more or less subject to modifications of the above general laws, on account of their own weight. As

a general rule of material beams, we may say that the strength of a beam increases as the breadth, as the square of the depth, and inversely as the length of the beam. Solid beams are weaker if the material is close around the centre, than if farther off from it. Solid cylinders are therefore the weakest form; hollow cylinders are stronger; but a rectangle is superior to either. A better form for beams is the T form, still better the double T, the hollow rectangle, or the cross + section beam.

In respect to the elasticity of beams, this rule is still more important. The resistance of a beam to the permanent alteration of form by a bending force, is in a direct ratio to the transverse section, and the square of the distance from the neutral axis. The neutral axis passes through the centre of gravity of the cross section. From this it follows that the resistance to bending a square beam increases as its width, and the cube of the depth of the beam. An elliptical is stronger than a circular section of a beam.

MENSURATION.

The surface of a Triangle is half the base into the height, and the surface of a Rectangle, Square, Rhombus, or Rhomboid, is equal to the base multiplied into the height. The area of the Trapezoid is as the perpendicular height between, and half the sum of, the parallel sides. The surface of the Trapezium is measured by multiplying the sum of the two perpendiculars, erected upon the diagonal, to the opposite angles, and dividing the product by two. The area of a regular Polygon is found by multiplying one of the sides into the whole number of sides, and the product into half the perpendicular which falls from the centre of the polygon upon one of its sides. The irre-

gular polygon is found by dividing it into triangles, trapezoids, &c., and finding their surfaces; by adding these together, the area of the polygon, as well as of any other irregular figure, will be found. The circumference of a circle is as the diameter into π, ($\pi = 3{\cdot}14159$,) or $2v : \pi$, in which v is the radius. The area of a circle is $v^2\pi$; or it is the square of the diameter multiplied by ·7854; or, more correctly, ·785398. The area is also half the diameter in half the circumference. The arc of a circle is $v \times {\cdot}01745 \times$ degrees of arc. The sector of a circle is one-half the arc in the radius. The area of a segment is found by finding, first, the area of the sector belonging to the arc of the segment, and then the area of the triangle formed by the chord of the segment and the two radii of the sector; the sum of the two will be the area in case the segment is larger than half a circle, and the difference will be the area in case the segment is smaller than half the circle. The largest square to be described in a circle is found by multiplying the diameter of the circle by ·7071; the product is the side of the square. The side of an equivalent square of a circle is found by multiplying the diameter by ·8862. The area of a circular zone, or the space included between two chords, is found by dissecting the zone into a trapezoid and two segments, and finding the contents of these, which, added, give the area of the zone. The surface of an ellipsis is equal to the transverse axis in the conjugate axis, multiplied by ·785398; and the circumference of an ellipsis is equal to the transverse with conjugate axis, divided by 2, the square root, and multiplied by 3·14159. The length of an arc of the parabola is four-thirds of the square of the abscissa, added to the square of the ordinate, and twice the square root of the whole. The area of a parabola is equal to two-thirds of the base into the height.

SOLIDS

Are measured by considering their dimensions in length, breadth, and thickness. The surface of a cube, or of any prism, is found by multiplying the perimeter into the length or height; the product is the surface, if we add the contents of the two ends. The surface of a cube is one of the sides multiplied by six. The contents of a cube, or any cylinder or prism, are equal to one of the ends, or base, multiplied by the height. The surface of a cylinder is equal to its periphery, multiplied by the length, and to this added the two circles on each end. The solidity of a cylinder is the area of the base with the length. The surface of a pyramid is half the circumference of the base into the oblique height. The solid contents are found by multiplying the base of a pyramid into the perpendicular height, and multiplying the whole by three. The contents of a wedge are found by taking twice the length of the base, added to the length of the edge, and multiplying by the height of the wedge and the breadth of the base; one-sixth of this sum will give the contents required. The surface of a sphere is equal to four times the area of a great circle $= L \cdot R^2$. The solidity of the sphere is the cube of the diameter multiplied by ·5236. The solidity of a segment of a sphere is equal to three times the radius of its base, added to the square of its height; the sum being multiplied by the height, and the product by ·5236. The solidity of a spheroid is equal to the square of the revolving or short axis, multiplied by the long axis, and the product again multiplied by ·5236. The solid contents of a paraboloid, formed by rotating a parabola upon its axis, are as the area of its base, times half its altitude.

The contents of surfaces or solids of any form may be found by dissecting the figures into well-known forms. These divisions may be triangles, trapezoids, circles or parts of circles, cubes, prisms, pyramids, spheres or parts of spheres, &c. In a practical way, the contents of a small body may be found by immersing that body in water, dry sand, quicksilver, shot, or something of the kind. The fluid or semi-fluid matter serving the purpose of measurement is to be contained in a well-adjusted box, of known capacity; at least the upper variable parts of which ought to be divided into inches and fractions of inches. Such an arrangement will at once indicate the contents of the body immersed.

CHAPTER III.

LAWS OF REST.—STATICS OF RIGID MATTER.

CENTRE OF GRAVITY.

If the centre of gravity of any body whatever is supported, that body will be at rest. The centre of gravity does not always fall in the mass of a body, but frequently in an imaginary point, as is the case in a hollow cylinder, or hollow sphere. If a heavy body is suspended by another point than the centre of gravity, that body will not be at rest unless the point is in the vertical line of suspension. The geometrical centre is always the centre of gravity, in homogeneous bodies. In regular plane figures, it is not difficult to find the centre, since the diagonals, diameters and radii of any parallelogram, regular polygon.

rhomboid, circle, ellipse, or line, meet in the geometrical centre; hence, in the centre of gravity. The centre of gravity in a triangle is one-third from the basis, in that line which is drawn from the middle of the basis to the opposite angle. In a trapez, the centre of gravity is in the crossing of the two lines which are drawn from the four centres of gravity belonging to the four triangles into which the trapezium may be divided; each triangle having one of the sides for its base. In a circular arc, we find the centre of inertia, if we multiply the radius of the circle by the chord of the arc, and divide by the length of the arc; the result will be the distance from the centre of the circle to the centre of gravity of the arc. A segment of a circle is then at rest, if we multiply the area of the segment by twelve, and divide this into half the cube of the chord; the resulting distance, measured from the centre of the circle, is supported. In a sector of a circle, we find the centre of force if we multiply twice the chord of the arc by the radius of the circle, and divide this by three times the length of the arc; the quotient will be the distance of the centre of gravity from the centre of the circle. If we multiply the radius of a circle by four, and divide the product by three times π, we shall have the distance of the centre of gravity for a semicircle, from the centre of the circle. The distance upon the axis from the vertex, equal to three-fifths of its whole length, is the centre of gravity in a paraboloid.

CENTRE OF GRAVITY IN SOLIDS.

The centre of gravity in a sphere is its geometric centre, as also in a spherical zone or segment. In a pyramid, or cone, the centre of rest lies in that line which is drawn from the centre of gravity in the base to the apex; one-

fourth of that line from the base will be the point. In a frustrum of a cone or pyramid, we find the desired point if we add the square of the sum of the radii of both ends, to twice the square of the radius of the greater end, and divide the sum by the difference between the square of the sum of the radii, and the product of the same; this, multiplied by one-fourth of the height, will give the point in question from the base.

The centre of gravity in any plane body may be found if that body — say a plain board or plank — is suspended on one corner, and from the same corner a plummet let down; where the plummet line passes, there is the line of the centre of gravity. If the direction of the plummet line is marked out, and the body turned and suspended by another corner, and operated in the same way, we shall have the centre of gravity in the point where the plummet lines cut each other. Another method is to lay the body on a sharp, straight edge, say the corner of an edged rule, and balance it; mark this line, and cross the body, or balance it, in another position, and mark again; where the two lines cross one another, we have the centre of gravity. In the same way, we may find the centre of gravity in a hollow arch, if it is not too large; for the centre of gravity in the segment is vertical upon the centre of the arch, and is half the width of the arch. If a rotary motion is given to a suspended body, the axis of rotation will always pass through the centre of gravity. If the form of a body is altered, the position of the centre of gravity is changed; if a man stretches out his arm or leg, the centre of gravity will be moved towards that arm or leg; and if the body is bent, so as to bring hands and feet together, the point of weight may be made to fall out of the body into the space between the hands and feet.

The point of gravitation for two or more bodies in one plane is found if we determine the distances of the various points of gravity from an imaginary line; the sum of all the weights of the various bodies converted into that line, gives the element to determine the point of gravity in the line. This experiment is repeated with another line crossing the first, from which the centre of gravity can easily be computed.

The centre of gravity of a number of bodies which are not in the same plane, may be found if we assume three planes, each cutting the others vertically. The distance of the forces from each plane, multiplied by the weight of each body, and all the momentums added and divided by the sum of the weights, will give the distance of the point of gravity from that plane. This process, repeated with each plane, will give the position of the point of force for the whole system.

Every body has a point of gravity, and, if that point is supported, the body is supported; from which it follows, that one and the same body cannot have two or more centres of gravity. The support of the centre of gravity is pressed with the whole weight of the body, proving that all the weight of that body is concentrated in the one point. In all cases where we endeavour to find the centre of gravity by construction, we assume the matter to be of uniform specific gravity. If this, however, is not the case, as frequently happens in practice, all calculations made without regard to the specific gravity of matter are vain; for in this case the contents are not as the specific gravities, which have been assumed in all theoretical investigations. The finding of the point of gravity is on this account often difficult, and there is scarcely any other means than by practical experiment. If the specific gravity of

matter in a body is uniform, the centre of gravity in a large body may be found by imitating it in a miniature form. In similar figures, the point of gravity is the same. If we reduce the four hundred feet span of a bridge to a few inches, we may find the centre for the mass of the arch by a small trial, and transfer this by measurement to the large arch. This, however, is only true in cases where the specific gravity is uniform.

THE EQUILIBRIUM OF MATTER

Is accomplished if the centre of gravity is supported by one or more immovable points. If a body is at rest upon a plane, and a force not perpendicular upon the plane is applied to its centre of gravity, the body, if it cannot move, will be upset, should the disturbing force be equal to the measure of its stability. If a body is not in immediate contact with its supports, but rests upon a medium — say props of stone, wood, or metal — then the lower points of these props, connected, form the basis of support. The stability of a body is greatest, the nearer the point of gravity is to its support; the heavier it is, and the larger is its base. If the centre of gravity is perpendicular above the point of support, the least motion will disturb its stability. If a perpendicular drawn from the point of gravity does not fall within the basis of the body, the equilibrium is violated, and the body will fall.

A vertical stone or brick wall is stable in proportion to its length, and the square of its thickness. Therefore, a wall which is twice as thick as another, is four times as strong; and a wall twice as long as another, is twice as strong; the height has no influence upon its stability, provided the wall is vertical.

The stress applied to pull down a wall is as the square

of its thickness; and twice the stress would require for resistance but $1 + \frac{1}{4}$, or $\sqrt{2}$. The resistance of a wall can be augmented by dividing the material into wall and braces, the latter of which are to be on the side where the pulling force is applied. Or if the same resistance of the wall is required, the amount of material may be reduced to $\frac{9}{14}$ by judiciously applied braces on both sides of the wall. If the material from which a wall is to be built is converted into a trapezoid section, where the top is but one-quarter of the base, the wall is twice as strong as if the same material had been employed in a wall with parallel or vertical sides, and of the same height. The stability of a square pillar is

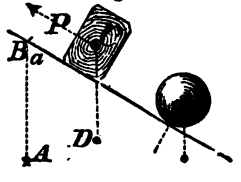
$$S = \frac{\frac{1}{2} D}{\frac{1}{2} H} \times P,$$

if D is the base, H the height, and P the weight of the pillar. A round pillar of the same base is not as stable as a square pillar; the proportion is as 39 to 44.

INCLINED PLANE.

If the base on which a body rests is not horizontal, the body may have two motions — a sliding and a rolling motion. It depends entirely on the degree of inclination or friction, whether a body can be at rest. If a body, fig. 25, is placed upon an inclined plane, AB, and the perpendicular CD, drawn from the centre of gravity of the body, falls within the base of it, the body cannot overturn, but will slide, in case the friction is not sufficient to hold it. If the body upon the inclined plane is a ball, it cannot be at rest,

Fig. 25.



as its perpendicular from the centre is not supported. The body C will be at rest with a force, P, equal to the angle of inclination, if we ignore friction. If the force is parallel with the inclined plane, then is the weight of C to the retaining force P as the length of the plane is to its height. And if the direction of the power P is parallel to the base of the inclined plane, C is to P as the base to the height of the plane. Any power acting in opposition to the descent of the plane will move the body, in case that power is in the least degree stronger than the relative gravity and friction united. If the force which acts upon the body is parallel with the plane, then the power required for motion is simply $P = (\cos \alpha + F \sin \alpha)$, wherein F is the quotient, or coefficient of friction. If F is one-sixth of the whole weight of the body C, which may be 1000 pounds, the force to keep the weight at rest will be if α is 60°, $1000 \times (0{\cdot}5 + \frac{1}{6} \times 0{\cdot}866) = 644{\cdot}3$ pounds; the smallest amount of surplus power will move the body. If the force is inclined to the plane, the above formula is to be divided by the difference. In this case the formula will be, if we include friction, and call that angle under which the force P will cut the vertical line AB, β:

$$P = \frac{\cos(\beta - \alpha) - F \sin(\beta - \alpha)}{\cos \alpha + B \sin \alpha}.$$

Or, if we substitute the above special values, the force to move the body will be a little more than

$$P = \frac{1000 \times (0{\cdot}5 + \frac{1}{6} \times 0{\cdot}866)}{0{\cdot}9659 - \frac{1}{6} \times 0{\cdot}253} = 698$$

pounds. Here is $\beta = 75°$ to the vertical line AB. In this formula, the coefficient F may be increased to the

annihilation of all other values; that is, the friction may absorb all the forces which tend to move C. The inclination of the inclined plane which makes the friction of C equal to the moving force, is frequently called the angle of friction. If we know the angle of friction, we want simply the angle of the plane, or the length and height of the inclined plane, to know the force which is required to hold a body in its position on such plane; for the product of the length of the plane in the force, divided by the height, is the force which will support the body. The force requisite to move a body up an inclined plane is readily confirmed by attaching a spring-balance to the body to be moved; in varying the angle of the plane, as well as the angle of force, the power is directly shown on the scale of the balance. In calculating the stability of props, arches, piers, abutments, &c., the theory of the inclined plane is eminently useful. Where the plane moves, or is to be moved, as in the case of a ladder against a house, or a prop inclined to support a weight, the coefficient of friction may become a compound force, resulting from the difference of friction on both ends of the plane. The general formula is the same in these instances.

THE WEDGE

Is an inclined plane, and is governed by similar laws of motion and rest. When the edge of a wedge is driven against an opposing body, the power with which the wedge will penetrate that body is in ratio to the sine of the half angle of the wedge, or to the sine of the angle with the face of the wedge in that direction in which the resistance opposes. The power which is required to drive in a wedge is, to one of the sides, as that side is to the base of the wedge, provided the resistance is in the vertical direction

Fig. 26.

upon the face of the wedge. The force which is required to drive a wedge, A, (fig. 26,) into a piece of timber, or anywhere else, is composed of the friction, F, and the resistance, R. On both sides of the wedge is the friction, F, which is in relation to the materials of which the wedge and resistance are composed. The force, P, which is applied to the head of the wedge, is the pressure, FR, on that part of the wedge which is in action. It is to be in a parallel direction to P, and is then equal to $\frac{1}{2}$ P; and the formula is

$$\tfrac{1}{2}\,P = R \sin \alpha + FR \cos \alpha.$$
$$P = 2 \times (\sin \alpha + F \cos \alpha)\, R.$$

If the resistance is the same, the power must be the larger, if F is equal to cos α; if cos α is larger than F, the wedge will slide back.

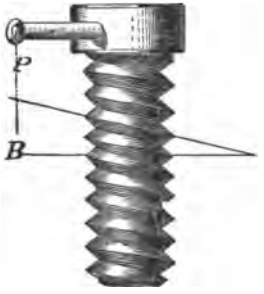
THE SCREW.

If we wind a thread in the direction of an inclined plane to the base of a cylinder, around that cylinder, we form a screw. The force requisite to move a screw is in proportion to the resistance, as the length of the circumference of the screw is to the height, or the distance from one thread to the other. The friction, a very important item, is not included in the above rule. The thread or ridge of a screw is frequently square, but in most cases sharp; in the latter case, it forms the section of a triangle. The curved line which is formed by the thread of a screw, is a helical line.

For calculating the effect of a screw, we can employ the

formula found to the inclined plane, making due allowance for friction. In a screw with a square thread, the friction will be simply as the pressure, increasing with the surface of the thread. In a screw with a triangular thread, the friction is a compound of the vertical pressure, added to the angle which one side of the thread forms with that line which is perpendicular to the axis of the screw. In fig. 27, the force P is always at right angles with the perpendicular, upon the base, PB, of the plane, for which reason we substitute 1 for $(90° - \alpha)$. And the formula will then be,

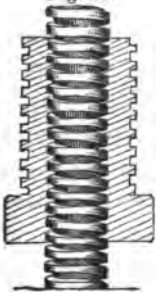
Fig. 27.



$$P = \frac{1 + F \times \alpha}{\cot \alpha - F},$$

by which force a resistance to the screw may be balanced. From this it follows that if F, or the friction, is equal to the height of the thread, divided by the circumference of the screw, the screw will be at rest. The power of a screw can be almost infinitely increased by turning both nut and screw, or by cutting a second screw within the core of the first, and moving both. This is illustrated in fig. 28. The thread of one of these screws is to be finer than that of the other; the difference in the height of the two threads is here the measure of effect.

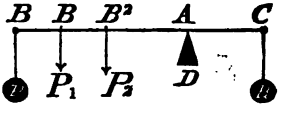
Fig. 28.



THE LEVER

Is one of the most interesting of the mechanical forces. A rod of iron, wood, or any other substance, forms a material lever; an imponderable line forms the mathematical lever. A lever is divided into three elements — the force, the fulcrum, and the resistance. The fulcrum of a lever can be either between the force and resistance, or at one end, near the resistance or near the force. The general rule which constitutes an equilibrium in a lever is, that "the resistance multiplied by the distance from the fulcrum, must be equal to the force multiplied in its distance from the fulcrum." If several weights at various distances are employed upon a lever, some on one and some on the other side of the fulcrum, then the sum of the product of all the weights in the distances is required to form an equilibrium in the lever. If a lever is not a mere mathematical line, but has weight by itself, then the weight of the lever on one side of the fulcrum is to be added to its respective force, and on the opposite side subtracted from it. If two or more levers act one upon the other, then the product of all the levers is the modulus of equilibrium. If, in fig. 29, a lever devoid of weight is represented, that lever will be at rest if the distance CA, multiplied by R, is equal to the distance AB × P. The pressure upon the fulcrum D is equal to the sum of R + P + P_1 + P_2. If there are more forces working on one or both sides of the lever, the sum of all these forces must be equal, to balance the lever. It is

Fig. 29.



$$AC \times R = AB \times P + AB \times P_1 + AB_2 \times P_2 +$$

All the forces can be concentrated into one point, which

point may be in the line of the lever, or in its prolongation. This point is found by taking the distances of each weight, multiplied by the corresponding weight; the sum of all these forces will give their centre of momentum. If one or more forces are moving a lever, say from its horizontal position, it does not make any difference in the calculation of the forces. The weights K, P, P_1, and P_2, may be more or less inclined towards the lever; the relative value of the forces is the same; the lever will be in all positions at rest, if it is at rest in a horizontal position. If, instead of a line, a plane is substituted, the same general laws are applied. If the sum of all the forces on one side of the axis of a plane is equal to the sum of all the forces of the other side of the axis, the plane will be at rest. If there are more planes than one, cutting each other in a common axis, they will all be at rest, if the sum of all the forces on each side of the axis is equal.

If the lever is a material lever, say a crowbar or handspike, or has in fact any form of matter, the calculations differ somewhat from the foregoing, inasmuch as the weight of the lever is to be considered. The calculations are not materially altered; but we have to bring the weight concentrated in the point of gravity on each side of the lever, and consider that weight as one of the forces, always computing it as a force working in a vertical direction. Gravity has but one direction, and the weight of the material lever is to be considered as such. In fig. 30, a lever may be represented by which a stone, R, is to be lifted. If the lever is an iron crowbar, eight feet long, and its weight 100 pounds, which latter is

Fig. 30.

concentrated in P_1, the middle of the bar; the weight of the stone may be 600 pounds, and the force in P 150 pounds. The formula for the equilibrium of the lever is

$$\text{Eq.} = \frac{PP_1 \times P_1 + PR_1 \times R}{P + R + P_1}.$$

If we substitute the real values in this formula, we shall find,

$$\text{Eq.} = \frac{\frac{8}{2} \times 100 + 8 \times 600}{150 + 600 + 100} = 6{\cdot}1$$

feet; that is, the frustrum is to be 6·1 feet from P. If a material lever is supported in one end, the force P_1 near the frustrum works downwards, and the force P on the opposite end to the frustrum works upwards, or is opposite to P_1. If the length of the lever is the unknown $= x$, but all the other factors are known, and each foot of the lever weighs W pounds; that lever will be in equilibrium, if the distance of the frustrum from P is = A. Now,

$$xP = AP_1 + \tfrac{1}{2}x \times W \times x = x^2 - \frac{2P}{W}x + \frac{2AP_1}{W} = 0.$$

$$x = \frac{P \pm \sqrt{(P^2 - 2AWP_1)}}{W}.$$

Here are two cases possible in which the lever may be in equilibrium; that is, the weight of the lever itself, or the lever and P together, may cause the equilibrium. If the weight of the lever and the nearest weight is larger than P, the lever cannot be at rest.

Scales and beams for weighing are constructed on the principle of the lever. The common balance is a lever, where both ends of the lever are equally long. In plat-

form scales, the lengths are generally in the proportion of decimals. In the steelyard, the distances are arbitrary. As general rules for constructing scales, it may be remarked, that, the nearer the fulcrum is to the centre of gravity, the more sensitive will the scales be; and the greater the distance of the fulcrum, above or below, from the centre of gravity, the more slowly will the scales work. In a steelyard, or lever scales of any kind, there is a line of gravity; and this line is to be below the frustrum. Steelyards and platform scales should never be used for a greater weight than that for which they are adjusted; for the weight will not be correctly given if the scales are overburdened. The material of which scales are made is generally flexible; and this is one cause of the difference; the other cause is the removal of the centre of gravity. Scales, if overburdened, generally show too little weight. The application of the simple lever is very extensive; it is used for pumps, crowbars, wheelbarrows, brakes, &c.

THE BALANCE.

This is a particular arrangement of the lever, and serves, like all balances and scales, to determine the weight of a body. There are two distinct kinds of balances, the scales and the steelyard—the equal and unequal lever. A balance is called more sensitive than another, when it moves with a smaller weight on one side than on the other. This sensitiveness is caused by the relative positions of the centre of gravity and the centre of suspension. If we lay a straight line through the two points where resistance and weight are suspended, that line will become the mathematical lever, of which the point of suspension is the frustrum. The position of the frustrum to the line of leverage decides the quality of the balance. The centre of gravity in the

mathematical lever is in its middle, and it does not make any difference if weights are suspended at each end of the line. When this centre of gravity and the frustrum fall in the same point, the lever, and consequently the scales, will be at rest in any position they may assume. If the point of suspension is below the point of gravity, the balance will move from its horizontal position at the slightest motion, because the point of gravity, falling on one side of the frustrum, increases the length of the lever on that side. If the point of suspension is above the point of gravity, the balance will always be at rest, if the weights at both ends are equal; no motion will permanently disturb it, because the point of gravity is always below that of suspension.

The laws which rule this subject show that the longer the balance beam is, the more sensitive is the balance. The motion of the beam, or the angle described by the tongue of the beam, is the greatest, the nearer the point of gravity is to the point of suspension. This angle is also the largest, when the weight of the beams and the weight of the platforms is the smallest. The angle of deviation is smallest when the point of gravity is farthest from the point of suspension. It follows from this, that a certain distance is in each particular case the most perfect. The smaller the angle of deviation, the quicker the scales will work; the two points are therefore not to be too close. To increase the sensitiveness of a scale, a small weight, put on the top of a long vertical tongue, will increase the angle of deviation, and show more distinctly the difference of the weights suspended at each end. These laws apply as well to the steelyard and platform scales, as to the balance with equal leverage. In respect to the latter description of scale, it is worthy of remark, that if a steelyard or a platform scale is ad-

justed to a certain quantity of weight, we cannot increase that weight and be correct; in this case, the matter to be weighed will, in most instances, be found too heavy. This depends on the position of the point of gravity. If the point of gravity in such scales — that is, burden and weight of scales — is between the point of suspension and the point of burden, as is always the case, then the burden will appear to be of less than its actual weight. The farther the point of gravity falls from the point of suspension, the larger is that difference. If a balance is so far overburdened as to bend the levers, the weight is never correct, because then the point of gravity is shifted from its proper place.

THE PULLEY

Is a wheel which may turn around its axis, and which commonly serves to lift weights. It is a common lever, which in practice requires reflection, on account of the rigidity of the ropes or chains used to put the lever in motion. The theory of the pulley is most simple, if we abstain from taking friction and rigidity of ropes into consideration. If the ropes are working over one pulley, or a system of pulleys, and are parallel with one another, then the effect is equal to the force applied to the rope of the fixed pulley. In the movable pulley, the effect is equal to twice the force. If the ropes are more or less divergent from the movable pulley, then the effect or power in the movable pulley is to the weight to be raised, as the radius of the pulley to the cord of the arc over which the rope passes. The power gained in the pulley is lost at the same ratio in speed. The rigidity of ropes in being bent upon a pulley is equal to the tension of the rope directly, inversely to the diameter of the pulley, and as the square of the thick-

ness of the rope; that is, its diameter. If C, by means of experiments, is taken as a determined coefficient, in reference to the rigidity of a particular kind of rope; the force required, or the loss sustained in bending that rope over a pulley is $= \frac{R^2 \times T}{C \times \frac{1}{2} D}$, wherein R is the diameter of the rope in twelfths of inches, T the tension, and D the diameter of the pulley. A fastened pulley will be at rest, if the force added to the above formula is equal to the resistance. If the force on a permanent pulley is less than the resistance, the latter will move it. To this formula is to be added the friction on the bolt in the centre, caused by the applied force and resistance, the weight of the pulley, and the weight of the rope. If we assume, in the above formula, D = 6 inches, R $\frac{1}{6}$ of an inch, T equal to the tension, or 500 pounds, the weight to be lifted. If the friction is equal to one-fifth of the whole weight, and C the coefficient of rigidity, $\frac{1}{3500}$. The force required to balance 500 pounds is =

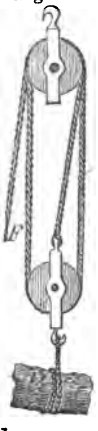
$$\frac{\left(D + \frac{1}{5 \times 24} + \frac{R^2}{3500}\right) \times 500 + \frac{1}{5} \times \frac{1}{24} \times 12}{\frac{1}{4} - \frac{1}{5 \times 24}} =$$

$$\frac{\left(\frac{1}{4} + \frac{1}{5 \times 24} + \frac{100}{3500}\right) 500 + \frac{1}{5} \times \frac{1}{24} \times 12}{\frac{1}{4} - \frac{1}{5 \times 24}} = 594 \text{ pounds.}$$

Here is $\frac{1}{24}$, the radius in feet of the bolt in the pulley.

The common pulley, or block, (as shown in fig. 31,) is generally double; one pulley is fastened, and the other

Fig. 31.



movable. Twice the number of movable rollers, divided into the resistance, P, to which the weight of the lower block is to be added, is the measure of power. The rigidity of ropes, friction in the pulleys, and other impediments, reduce the nominal effect to almost one-half. As the rigidity and friction increase with the resistance or tension, there is hardly any diminution of that loss by greater tension. If a certain load is to be raised by means of pulleys, it will not be advisable to expect more than half the effect of the applied power. Improvements in blocks to diminish friction will not advance the result much, in case the rollers have not been too small, or the pins too thick. In common blocks, the friction around the pin is hardly more than one-hundredth of the tension.

The rigidity of ropes is a subject worthy of much consideration. The difference in the size of the rope, the mode and material of its manufacture, and the occurrence of tarred or oiled rope; all these circumstances have more or less influence upon its rigidity. To insert tables of rigidity would be almost useless, on account of this variety and difference in ropes. In all important cases, it will be the safest plan to try the rigidity of a particular rope by bending it over a pulley, say of one foot diameter, and marking the weight required to bend the rope as far as is thought requisite, adding the weight of the rope to the weight applied. The value found may be inserted in computing the formula.

THE WHEEL AND AXLE

Is closely related to the lever. All wheel machines, cranes, windlasses, horse-whins, &c., belong to this power. If the wheel (fig. 32) is a perpetual lever, turned or held

Fig. 32.

at rest with a power, P, the resistance R can be stronger in proportion as the diameter of the larger wheel is to the smaller wheel. The latter may conduct its power to another wheel, B, or be prolonged in the direction of its axle, and form a shaft to a windlass. If the large wheels, A, B, C, are equal, and the small wheels are also equal, then the power, in being transferred from A to the small wheel *c*, will augment in three times the ratio between the first large and small roller. If the diameter of A is five, and the small wheel one foot, then the power will increase, in being transferred from the large to the small wheel, five times. In the second wheel it will be again augmented five times, and in the third wheel five times. This, taken together, makes $5\times5\times5=125$. The power, therefore, increases as the squares of the ratios. The resistance R on the small wheel *c* can therefore be 125 times more than the applied force P. The velocities will increase in the same ratio if we convert the power into motion, by reversing the application of force. The loss in force will be in ratio to the gain in speed. If we disregard friction, then the gain in power or speed is in the ratio of the difference between the two wheels which are on the same axle, the differences being multiplied one by the other. Thus, if *b* is to A as 1 : 5, *b* to B as 1 : 7, *c* to C as 3 : 8; then the whole train will be, if P is 10, $R=10\times5\times7\times\frac{8}{3}=931$; this may be either feet or pounds. In practical applications of this rule, we have to consider friction between the wheels and on the axles, counting the diameter of the bore, in case the wheel turns around a pin, as is the case in blocks; if the wheels turn on axles, we of course take the diameter of the journals. The friction

in windlasses, cranes, and similar machines, is often important, but can be easily computed by referring to the tables of friction. In raising weights upon considerable heights, the weight of blocks and ropes, with the rigidity of the latter, and the friction for all, is to be considered. The thickness of the rope is also an object, as it increases the diameter of the pulley, particularly if the rope passes more than once around the shaft.

PARALLELOGRAM OR ANALYSIS OF FORCES.

Any force may be assumed to be concentrated in one point, and it may also be said that a force consists of matter and motion. If a force in a certain direction meets another force in a different direction, both forces will be affected to the amount of the opposing force. One point of force does not necessarily fall together with other points of forces of the same body; their relative amount of force constitutes the common centre of the forces. Two forces of equal strength, meeting in opposite directions, in a straight line, annul each other. If the two forces thus meeting are unequal, there can be no rest; there must be motion in both forces. Two or more forces in the same direction concentrate in one point, in which point the sum of all the forces is expressed. An accumulation of forces in one point is equal to one force meeting another in an opposite direction. If a number of forces concentrated in one point are at rest, the addition or subtraction of another number of forces at rest, cannot cause motion. A number of forces in different directions upon one point, are at rest in one point, if the forces balance each other. If unbalanced forces meet in one point, there is motion in that point. If a number of forces are at rest, and another number equal to the first meet in the same point, there is

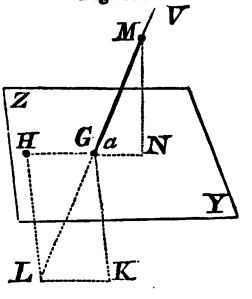
rest. Two equal forces, meeting in opposite but inclined directions, in straight lines and the same plane, cannot be at rest; for these forces are not balanced, and motion will result in a third direction. The third direction in which the two united forces move, is in a direction composed of the two forces. If two forces meet under a right angle, the square of the resulting force is equal to the squares of the composing forces.

The direction of two forces forms with a medium direction such angles as will produce a rectangular triangle, provided the two forces meet in an angle of 90°. This is the reason why three forces may be represented at rest in a parallelogram, because the two side forces may be represented in two lines, which show the direction of the forces, and their lengths show the magnitudes of the forces. The diagonal represents the third force, with which the two side forces will move or be at rest. This operation is very easily performed on paper. From this it follows that any force may be divided into as many forces as we choose, in a mechanical way, by assuming one force as a diagonal to any number of parallelograms. These divisions of forces may be extended to any magnitude and direction, provided always that the main force forms the diagonal. All these forces will be at rest if not extended beyond the diagonal. If we draw a perpendicular line upon a given force, or a number of forces, from any point we choose, the distance from that point to the force or forces, multiplied by the force, forms the momentum of that force or forces in the assumed point; and it is called the centre of the momentum. If three forces, which act in different directions, are at rest, then the momentums of the three forces must be equal, if constructed from any point in the direction of one of these forces.

The analysis of forces, commonly called the parallelogram of forces, is the most important of all the branches of theoretical mechanics, the study of which cannot be too highly recommended to the young mechanic and machinist; it affords him the opportunity of directing his mind to the analysis of machines, forces, and motions. We cannot do justice to this subject, nor indeed is it our province.

A FORCE UPON A PLANE.

Fig. 33.



If a plane (fig. 33) YZ is met by a force V, in the direction MG, the force not being in contact with the plane, draw MN perpendicular upon YZ; then is MGN = α, or the angle of projection in which the force V cuts the plane. The plane receives then a pressure equal to V in the prolongation GL. If we prolong GN to H, and describe the parallelogram GHLK, then is GL equal to V, because GH = V cos α, and GK = V sin α. If P is the force caused by V upon the plane, and Q the perpendicular pressure upon it, then is P = V cos α, and Q = V sin α.

THREE FORCES.

If, on the point G, (fig. 34,) three forces, P, P_1, P_2, are pressing, in the directions GA, GB, GC, which may be perpendicular one upon the other; to find the force V and its direction. To these three forces we draw the parallelopipedon AGBCEDHF, and then draw the diagonal DG; this latter is the united force of P P_1 P_2.

Fig. 34.

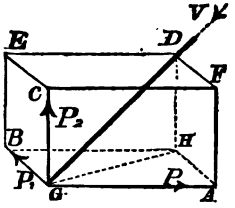
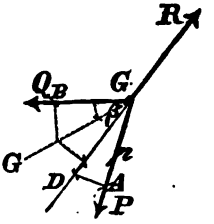


Fig. 35.

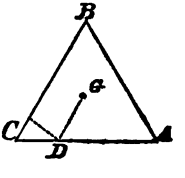


Three forces act in different directions, (fig. 35), PQR, and are at rest in G. If G receives a motion from some cause, and that motion is in the direction of G_1, then every force is moved parallel with the other. If we draw G_1 Q perpendicular upon GQ, then is Q moved for a distance equal to GB. The same is the case with the other forces, in proportion to their angles. If we perform this operation with the other forces, we find that all the forces where G may be are at rest, or neutralized. If P is the force and Q the resistance, and AG and GB are distances; then is P : Q : : BG : GA. Or, in words, the force P is to Q, the resistance, inversely as the distances they move in parallel directions.

This subject at first sight appears to be rather intricate; but, considering its general application in practice to suspension and truss bridges, stays, and props, it is well worth close attention.

DISTRIBUTION OF PRESSURE.

Fig. 36.

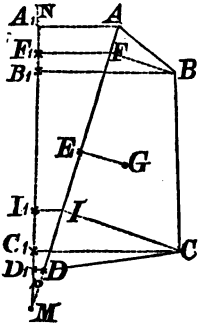


If an inflexible plane, say a triangle, (fig. 36,) is supported in the three points ABC, and a force or weight presses upon it in G; the pressure by a weight P upon the three supports is then P=A+B+C. If we assume BC as the axis of the forces,

or momentum, then is $CD \times P = CA \times A$, provided GD is parallel with CB. It is also, if AC is the axis, $DG \times P = CB \times B$. By this we find the pressure upon A to be, $A = \frac{CD}{CA} \times P$; and the pressure upon $B = \frac{DG}{CB} \times P$; upon C the pressure is $C = \left(1 - \frac{CD}{CA} - \frac{DG}{CB}\right) \times P$. If $CD = \frac{1}{3}CA$, and $\frac{1}{3}BC = DG$, the centre of gravity is the point G, and the pressure upon ABC is $\frac{1}{3}P$ each. If the three points are in a straight line, this law cannot be applied, because only two points support P.

If four supports are under the plane, and this should be a rectangular figure, then the pressure of each of the four points is equal to $\frac{1}{4}P$, provided the pressure is in the point of gravity. If the latter is not the case, we may then solve the problem generally, and proceed as follows. If,

Fig. 37.



in fig. 37, ABCD, the pressure P is in G; if further BF and CI, also GE, are perpendicular upon AD; then is, first, $P = A + B + C + D$; and second, $DE \times P = DA \times A + DF \times B + DI \times C$; also, third, $GE \times P = BF \times B + CI \times C$. These three equations are not sufficient to determine the pressure on each of the four points of support. We arrive at this if we draw the lines AA_1, BB_1, CC_1, DD_1, FF_1, II_1, perpendicular upon MN. If we mark these lines with their corresponding letters, A_2, B_2, C_2, D_2, for AA_1, BB_1, CC_1, DD_1, and $DM = x$. The mode of operation is to assume a motion in the four points caused by the pressure; this motion, no matter how small it might be, would form an inclined plane with the hori-

zontal plane; the distances caused by that plane or depression are represented by MN, and the angle by z. By a series of equations we arrive at the fourth equation, which is $AD \times B_2 \times (C - D) + DF \times CI \times (A - D)$; this is $= (B - D) + BF \times DI \times (A - D)$. By means of these four formulas, the value of the four unknown quantities may be found.

PRESSURE AGAINST WALLS.

When a beam, rafter, or other matter, is leaned against a vertical plane, resting upon a horizontal plane, the pressure against the latter is then as strong as if the rafter were standing vertically; against the vertical wall it presses with a pressure equal to that on the horizontal plane horizontally; this horizontal pressure is less, the more the direction is that of the vertical. In this calculation, the rafter is assumed to be without weight, and perfectly rigid. If two inclined rafters meet, they will press to both sides; and this pressure increases inversely as the angle it forms with its base. This pressure increases also with the weight of the rafters and their burden. The rafters of a house press towards their horizontal fastenings with a force which is expressed in the following formula, in which S is the horizontal pressure upon their plane; h, the height from the base to the upper or opposite angle; a, half the length of the base; b, the length of the rafter; g, the weight of one foot of the length of the rafter, including its burden. If the height is 4 a, or twice the length of the base; that is, $h = 4\,a$; then is $S = a \times g \times \frac{\sqrt{17}}{8} =$ $\cdot 5153 \times a \times g$. If $h = 2\,a$, then is $S = a \times q \times \frac{\sqrt{5}}{4} =$

$\cdot 559 \times a \times g$. If $b = 2\,a$, then is $S = \frac{a \times g}{\sqrt{3}} = a \times g \times \frac{\sqrt{3}}{3}$ $= \cdot 5773 \times a \times g$. If $a = h$, the pressure is then $S = a \times g \times \frac{\sqrt{2}}{2} = \cdot 7071 \times a \times g$. If $h = \frac{a}{2}$, then the formula is $S = a \times g \times \frac{\sqrt{5}}{2} = 1 \cdot 118 \times a \times g$. For $h = \frac{a}{4}$ is $S = a \times g \times \frac{\sqrt{17}}{2} = 2 \cdot 06 \times a \times g$. The latter pressure, or a flat roof, presses four times as strong as the highest roof. This is of great interest to everybody who constructs buildings, bridges, or machinery.

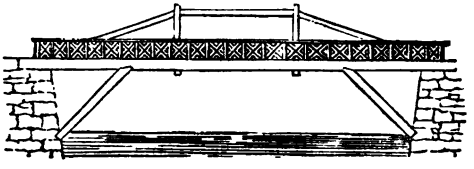
VERTICAL PRESSURE.

If a vertical pole is supported by stays or braces, such stays will have a tendency to lift the pole, and may lift it if they have motion. The shorter the stay by the same angle to the horizon, the more force they exercise in lifting the pole; and the smaller that angle, the less force is required to keep the pole down. If a stay of a certain length is inclined at an angle of 45° to its base or the horizon, it will suffer the least stress, and is therefore the strongest. Any braces, no matter where, are the strongest if they are inclined at an angle of 45° to their respective bases.

BRIDGE WITH BRACES.

If a girder, or any beam, is supported at the two ends, and in addition by two braces from below, as in fig. 38, it is the rule that, under equal conditions, the longest brace presses the most heavily against the abutment; the smaller the angle which the brace forms with the abutment, the less pressure is against it. If the braces are on the top

Fig. 38.



of the girder, and the girder suspended in them, the same rule which is developed by the rafters can be applied. If it is desired to calculate a bridge by this rule, not only the weight of the bridge is to be taken into account, but also the accidental load which it may bear, and the increased force caused by the motion of bodies passing over it.

ARCHES.

If stones or any other material form an arch, upon which besides its own weight no other force is applied, and whose joints are perfectly smooth, without friction or adhesion; such an arch will be at rest, and every stone in it will be at rest, when the weight of one part of the arch, from the keystone downwards, is to the weight of the next part, upon which the first part rests, (these parts being either single stones, or composed of a number of pieces,) as the tangent of that angle, which the lower plane of the arch-stone forms with the vertical drawn through the centre of the arch; or, to the difference of the tangents to the angles which are formed by the joints and the vertical line. Or, in other words, the weight of two stones, or parts of the arch, calculated from the key-joint, must be as the tangents of those angles which are formed by the joints with the vertical. Under these conditions, all the stones are at rest. If all the parts of an arch are at rest, then the pressure in every joint upon the part below it, or the

total amount of pressure against the abutment, or schuback, is equal to the horizontal pressure against the keystone, or the vertical joint. The vertical pressure of a part of the arch, calculated from the vertical joint, is equal to the mass of that part. It does not make any difference whether the arch is composed of solid matter, or of a number of parts; its strength is always the same. The thickness of an arch, or the length of the joints or stones, depends in some measure on the form of the arch; that is, on the inner curve, if it should be a circle, ellipse, catenary, or other curve. It depends also on the pressure upon the arch, and leads to calculations beyond our limits. If a curve for any arch is decided upon, it is not right to take that curve for the inner line, but to lay it in the middle of the thickness of the arch, making it the pitch-line from which the construction of the joints is to be directed. The most perfect curves for arches, uniting elegance with strength, are the catenary, the parabola, ellipse, circle, &c. The catenary has the advantage over any other line, in so far that, when the joints of the arch are vertical upon the catenary — that is, vertical upon the respective tangents — and the catenary forms the middle line of the arch, all the stones in the arch are at rest. The pressure of an arch against its abutments is found by considering the schuback as a termination of the arch, and finding the horizontal pressure by converting the vertical pressure into it, which can be done by means of the parallelogram of forces. In all these demonstrations, we have assumed that no other force acts upon the arch but its own weight; this, however, is seldom the case in practice. An arch always has some burden to carry; this burden may be concentrated into one point, or distributed over the whole length of the arch. This subject is regulated by the laws of the

distribution of forces upon beams or girders. If, besides a permanent burden at rest, the arch is to carry movable weights, as is the case upon bridges, the motion of that burden and the consequent momentum are to be brought into calculation.

In practice, the joints of an arch are always filled by cement, or mortar. If this mortar is as hard as the stone itself, and free from coarse grains of sand, this circumstance does not interfere with the above rules; the stones may even be cracked, provided the direction of the fissure is in the direction of the joints. The above rules apply to the arch if there is nothing in the joints, not even friction between the stones. If an arch is not constructed according to these rules, it is liable to breakage, because its strength depends in a great measure on the strength of its materials; and as mortar may drop out, or be crushed out of the joints, or one or more stones break, the arch is liable to fall in consequence. Mortar and strength of material increase the value of the above rules; but it is necessary to apply both perfectly. In erecting an arch which is to carry movable burdens, it is necessary to consider the changes which cause a part of the arch to be pressed out of the curve, in consequence of a local force which is stronger than the gravity of the arch; if such should happen, the arch is liable to destruction.

ABSOLUTE COHESION

Is that quality of matter which is shown in the resistance it offers to being torn asunder. If a piece of No. 10 iron wire bears a tension of 2000 pounds before it breaks, ten wires will bear ten times 2000 pounds; and if the sections of 50 wires of this number form the contents of one square inch, then a square inch of iron composed of that wire will

bear the stress of 50×2000 pounds before it is torn, provided the wires are so arranged that each will carry its full weight. It is therefore necessary that each wire should have been stretched by a general measure.

If a series of No. 10 wires are combined into a rope or cable, and fifty wires, or one square inch, carries 100,000 pounds, it does not follow that a bar of wrought-iron, of one square inch, carries an equal weight, not even if the iron is of the same quality. And if a solid iron rod, of one inch square, carries 50,000 pounds, it does not follow that a rod of ten square inches in the section carries ten times as much. The same quantity of iron will carry ten times as much when separated, and suspended under equal strain; but if welded together, their capacity for resistance is weakened. With this explanation, the tables at the end of the volume will be understood.

This rule applies to almost every kind of material, and varies only in degree. In iron, particularly wrought-iron, we may confidently assert that a rod of one inch square, made of the same iron as No. 10 wire, will carry but half the weight computed from the experiments made on the wire; and a three inch rod, or nine square inches in one rod, will carry one-fourth less, often one-half, to the inch, than the inch rod. In wire, the cohesion is considerably greater, if the wire is drawn hard, than if drawn soft; in many instances it amounts to a difference of thirty per cent. When good wire carries 130,000 pounds to the square inch when drawn hard, it will carry but 100,000 pounds, or less, when drawn through only one hole after annealing. The hard drawing may, however, be carried too far, so that the iron will lose all its softness, and break suddenly when burdened in the least degree beyond its strength. Such wire would not answer for bridges, or for

any other purpose where it had to carry heavy burdens, and where all its cohesion was calculated upon. Too soft wire is equally as objectionable as that which is too hard; for it will be permanently stretched, instead of recovering, after the accidental burden is removed.

All materials are subject to great variations in respect to strength, depending on form, size, and composition. In all cases where important results are to be expected, and where the cohesion is tasked to the utmost, it is advisable not to depend upon the tables for strength; it is best to make experiments upon the very material under consideration. The engineer is not always the manufacturer of the materials; and he frequently finds that the machinery or material upon which his calculations are based, is unfit for the purpose intended. On this account we should particularly scan the iron to be used, partly because it is the material most extensively employed in the construction of machinery, and partly because the ore from which it is made differs very greatly, and leads to a difference in the quality of the metal produced. The iron business, though rapidly growing, is yet in its infancy; and many are engaged in it who do not understand how to make the most of their crude materials. With the other metals it is less difficult to work; copper is generally uniform in quality, and so is lead, tin, &c. In respect to wood, it is to be remarked that, when one inch of wood carries a certain weight, it does not follow that 100 inches carry 100 times as much. The heart of a tree is not as strong as the fibrous wood growing around it; and the strongest wood is that which grows about half-way between the periphery of a tree and its centre. The degree of warmth or heat has a decided influence upon the cohesion of materials, generally weakening it; but this cannot be laid down as a rule, particu-

larly where motion is a part of the force to be resisted. The texture or aggregate form of the material deserves particular attention. A rod of fibrous iron may carry 100,000 pounds to the inch; while a rod made of the same material, but granulated in its fracture, will carry but 50,000 pounds to the inch. The fibres of wrought-iron are always an indication of strength; but in the application of such iron we are to be cautious. If the iron is impure in its elements, or has been badly worked, it may be very fibrous, and also strong; but in exposing it to a cherry-red or welding heat, it loses all its fibres, and is converted into brittle granulated iron. This happens frequently with puddled iron, and sometimes also with charcoal iron. As parts of machinery which are made of wrought-iron are in most instances exposed to the forge-fire, and forged to a greater or less extent, it is evident that iron which does not retain its fibre after receiving a welding heat is not to be trusted. The safest way is to employ nothing but good charcoal iron for machinery, or any other purpose where strength is required, in case any smithing is to be done at the iron before it is put to use. Where iron is exposed to heat, as in steam-engines, the very purest and best kinds only should be used, with the exclusion of all doubtful iron, particularly puddled iron. In steam-engines, the iron is exposed to a low, but constant heat, and, if not very pure, becomes granulated. Very fibrous puddled iron may carry 80,000 pounds to the inch, when newly made; but it may in a short time be converted into granular iron, and be inferior in strength to cast-iron; its cohesion may in consequence be reduced to 20,000 pounds. All wrought-iron of a fibrous character is converted into granulated iron in the course of time, when exposed to heat, no matter how low that heat may be; the changes of the atmosphere,

even, are sufficient for this purpose. In machinery where wrought-iron is used, too much attention cannot be paid to this subject; and if great strength is required, and the changes in the iron can be detrimental to the work, steel should be substituted. This has greatly the advantage over fibrous iron, because its strength is not impaired by time, nor by any degree of heat beyond a red heat. Steel is usually made of the best material, and in fact cannot be made of impure iron; for then it ceases to be steel.

The tables of cohesion, whether absolute or otherwise, are generally computed to the tearing of the material; in so far, such tables are useless for practical purposes. Our calculations should never go farther than to that point where the permanent form of the material is unaltered; for if its form is once altered, it never returns again, and the solidity and form of the structure is changed in consequence. Calculators should never expect more of any material than the excess of elasticity; beyond that, it is unsafe to trust. If any material, after exposure to certain forces, does not return to the form it had before the force was applied, it is an evidence that it has been burdened too much.

ELASTICITY OF IRON.

Experiments made on iron wire and iron rods have shown that a hard drawn iron wire will carry, without any permanent alteration of its form, two-thirds of the weight which is necessary to tear it asunder. By three-fourths of that load its elasticity is unimpaired. Soft-drawn wire does not return by two-thirds of the load, and stretches permanently if the force is seven-eighths of the load, to ·005 longer than its original length. Rods of iron, of one inch square, which may carry 60,000 pounds before they

are torn, stretch permanently by a load of less than 20,000 pounds. The best wrought-iron cannot bear more than one-sixth of its load without being permanently altered. These data apply only where the material is permanently at rest; if motion or accidental increase of burden happens, the above rules and numbers are considerably modified. As elasticity in material varies as much as its strength, and does not follow the same rules as cohesion, it is advisable to experiment in each particular case where important structures are to depend upon the smallest quantity of material.

THE STRONGEST FORM OF MATTER

Relative to absolute cohesion, is not and cannot be positively determined; but as a mathematical law, it may be stated that the strongest form of resistance is that section of the rod which is equal to its burden; that is, the weight of the rod itself. In practical cases, this law is equally true; but it is to be modified so far as the mode of manufacturing the rod has influence upon the law. If we split a tree in half, we do not have quite the strongest form; for the heart of the tree will not bear as much as the outer wood. This law is only true if the material is uniform in its mass. With regard to iron, we may remark that cast-iron is stronger in proportion to the amount of surface it offers. Wrought-iron of the same kind is also dependent on form; the round form will not bear as much as a square bar, and that less than a flat bar. Sheet-iron is the weakest of all forms. The form of wire is most favourable to absolute cohesion.

If a rod of considerable length is suspended, and has to carry, besides burden, its own weight also; the weight of the rod is to be taken into the calculation, or serious diffi-

culties may occur. If, for example, the chain or wire cable of a suspension bridge is not taken into consideration, the bridge may break in consequence. Wires or chains for bridges should be tried, singly, with the amount of force they will be required to sustain. For this purpose, the whole length of the wire for one cable is suspended between two poles, well fastened in the ground; at one of these poles is a windlass, upon which the wire is wound. The wire is fastened to the other pole, and wound up by the windlass to a certain deflection from the horizontal line. That deflection is the measure of its strength, and is calculated according to the rules of the catenary, that being the curve described by the wire.

As suspension bridges may be considered the most practical bridges in our country, it is desirable that the principles of their construction should be accurately known; but, as their full calculation is a somewhat difficult mathematical problem, we cannot furnish all the particulars bearing upon this question in the limited space and elementary tendency of this book. It may be laid down as a rule, however, that previous to the erection of a suspension or wire bridge, the strength of the wire should be ascertained. It is not necessary to try every wire; but a portion of that to be used should be tried promiscuously. If we know the weight of the wire per foot long, and the distance from one pole, where the wire is fastened, to the other, we know the weight of the whole length; or, if we cannot calculate the length of the catenary, we measure it. When a wire is suspended in the manner we have described, and wound up, and it breaks in one point of its length, the force which breaks it is equal to the vertical tension in that point, and to the weight of the wire or chain from that to the next point of suspension. The vertical tension, how-

ever, is equal to the horizontal tension; from which it follows, that the horizontal tension in the lowest point of deflection is equal to the tension on the points of suspension, or at the windlass. The tension on the whole length of the catenary is as the square root of the radius. If we find practically, in one case, the strength by which the wire breaks, the strength of the other wires is then as the square roots of the radius to the curve formed by the deflection.

RELATIVE STRENGTH, OR RELATIVE COHESION,

Is that strength by which a body is broken, such as beams, and similar forms. The laws relating to this subject, to be developed fully, would require more space than we can afford; but, for practical purposes, we may show the relation of various materials to each other. If a piece of cast-iron is broken by 24 pounds burden, the same form and size of oak will break by 8 pounds; there is, however, a great diversity in the quality of oak wood, as some of it will bear equal to cast-iron. Pine bears from 8 to 13 pounds, limestone 7, sandstone 6, and common brick 2 pounds. The advantages arising from the forms of beams, we have spoken of before.

If a cast-iron beam is supported on both ends, and its height and length are known, and also the weight which it is to carry; we find its width by multiplying its length between the supports in feet, by its load in pounds, and divide this by 850 times the square of the height of the beam in inches. The resulting quotient is the width in inches. If the width of the beam is known, and we want the height, we multiply the length by the load, and divide the product by 850 times the width, and extract the root of the quotient. If the load is not in the middle, but

more to one end of the beam, then multiply the short end by the long end of the beam, and this by four; divide the whole by the whole length of the beam; the quotient is now equal to the length in the above rules. If the load is equally distributed over the beam, the latter will carry twice as much as if the load was in but one point, in the middle; in this instance we take but half the load, and apply the above rule. If the beam is fastened at one end only, and the other end is to carry the load, the same rules are applied, except that we take 212 instead of 850. This rule refers to the best kind of iron.

The most perfect form of beam to carry, by a given section and a certain weight, the heaviest load, is the parabola, such as is generally given to the cast-iron balance-beams of English steam-engines. The curve belonging to both sides of the beam is a parabolic curve. The double T section, such as is generally given to beams, is the strongest form which can be made of the material. In computing the sizes of beams, the weight is always to be considered.

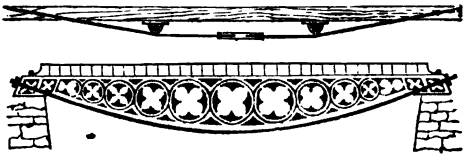
All portions of machinery which are intended to offer resistance to rupture, are subject to these rules. The cogs, rims, arms and spokes of wheels, steam-engines, girders, &c., come under this class. Machinery which is exposed to vibrations, should be as much stronger as the weight of the load is increased by those vibrations.

There is such a variety in the quality of materials, that it is difficult to form practical formulas which cover all cases. The few experiments made by scientific men are valuable in practice only so far as they show the relative strength of the variety. If good work is intended to be made, it is advisable to subject the material to an actual trial of strength. Materials, such as iron, wood, &c., vary

too much for us to depend on general laws, based upon one or two facts. If a trial is made of a rod or beam of a certain size, on a small scale, the law upon which the callations are based is, that the strength of a beam increases as its width, as the square of its depth, and inversely as the length of the beam; in which rule the imperfections coexistent with size or form are to be considered.

When we intend to apply beams of permanent form, the operation is extremely difficult; for all beams, without exception, will settle in the course of time; not only the load, but the changes of temperature, afford a permanent cause of this settling. Iron is not as liable to these permanent alterations as wood; but we cannot consider even iron as permanently elastic matter. The difficulty increases with wood; and, in respect to these alterations, we have no facts upon which to base general calculations. This subject may be considered an unexplored field of mechanics. The difficulty in ascertaining facts of this kind is chiefly owing to the time over which such experiments must be extended. It is of no use to make an experiment of elasticity in one day, and consider it settled. Such experiments are to be extended for years, on the same piece of material, or they are worthless. If a certain weight will bend a piece of iron or timber to a certain degree in twenty-four hours' time, and the iron or timber returns to its original form when the load is removed, it does not follow that if the load were extended for forty-eight hours, the material would return to its original form. After the load had remained for three days or more, the material might be permanently bent. These are serious objections to the application of beams for bridges; for there is no question that all beams will sink in the course of time, even with the lightest load. There is no such

Fig. 39.



thing as permanent elasticity in any rigid material; and the only possible way to construct a beam which will return to its original form after the load is removed, is a compound beam, put together in such a way that the permanent alteration of one material counterbalances that of the other. Compound beams are frequently applied, and are made of wood and wrought-iron, or cast and wrought-iron, as shown in fig. 39. Cast-iron and wooden beams are constructed on the same principle. The tubular bridge in England, (the rail-road bridge over the Menai Straits,) is a compound beam.

STRENGTH OF A CHAIN-LINK.

Theoretical investigations show that the direct strength is always greater than the relative strength, and that, to make the latter equal to the first, the width of the link ought to be infinite; it also follows, that the longest link has the weakest relative strength. The strongest form, or the greatest amount of material, in a chain, is therefore to be in the short bands of the links, where they meet. If the material is thin, such as wire laid over a pulley, all the strain is converted into absolute cohesion, and the link in the bend is as strong as any other portion. If the size of the iron of which a link is made guaranties a certain strength, and if the welding of a link is so well performed that that point is equal in strength to the original bar of iron, then

the chain-link will carry about half the weight belonging to the absolute cohesion of the material. It follows from this, that a chain will be but half as strong as a single bar, by having an equal amount of the same quality of material. The strongest form of chain-links may be mathematically demonstrated; but, for practical purposes, the subject is scarcely worth the labour.

STRENGTH OF AXLES.

If shafts, in addition to their own weight, are loaded with a burden, that burden must be taken into consideration in determining the strength of the axle. If a shaft has one or more pulleys to carry, and, besides these pulleys, the strain of their belts, that strain and the weight of the pulleys and belts is considered the load of the axis. If a railroad-car axle is made to carry a load, that load and the accidental vibrations caused by the joints and curves of the rail, or any other cause, must be considered. In the latter case, the pressure caused by the slanting form of the wheel-tire and the slanting top of the rail, is to be taken into calculation.

RESISTANCE TO COMPRESSION.

When rigid matter is so strongly compressed by a force or load as to cause rupture, the resistance to compression has been overcome. This rupture may be of two kinds: one, when the pressed body is so short as to be crushed into parts from its axis; and the other, when the pressed body is long, so as to bend before it breaks. In all calculations of this kind, the length of the body is to be considered. For matter of the same quality—that is, the prism or body—exposed to crushing, the law is, that the resistance to crushing is as the cube of the thickness, multiplied

by the width, and this divided by the square of the length. If we know the resistance to rupture or elasticity of matter of a certain size, and apply this rule, we find it for any size we want. It follows from this, that in columns or prisms of equal length and thickness, the resistance is as their width; and in equal lengths and widths, it is as the cube of the thickness: if width and thickness are equal, or if the column is square, the resistance is inversely as the square of its length. These laws are easily applied, and need no comment. It follows that the strength of a round column increases as the fourth power of its diameter or mass, and inversely as the square of its height.

With equal masses in a round column, the hollow column is by far stronger than that which is solid. The best form for cast-iron columns is to make the inner diameter five-eighths of the size of the exterior diameter. The ring thus formed of the section of the column increases in strength according to the thinness; but the size of it must be kept within practical limits. If, in casting a hollow column, the core is driven to one side, the column of course cannot be loaded to its full resistance; it will not carry more than the thinnest part of it is strong enough to bear. If, therefore, hollow columns are advantageous, particular care should be taken in manufacturing or casting them.

RESISTANCE TO TORSION.

When a body is fastened at one end, and a force applied at the other end; or when the force at one end is greater than at the other end; or when the forces at the ends are in opposite directions, and are so applied as to twist the body; the body is exposed to rupture by torsion. The power which is required to tear a body asunder by these

wrenching forces, increases with the torsion, the thickness of the body or its section, and inversely as the length of it. If a shaft is not loaded with other machinery, or with particular pressure, and has to carry its own weight only, and transmit the power of the driving machinery, its thickness increases only with its length. The weakest parts of shafts are generally their journals; and as these ought to be the strongest, we will confine our remarks to them, though those remarks may be applied to the whole shaft. The journals are not only exposed to torsion, but have the whole weight of the shaft and its wheels to bear, to which the friction is to be added. If the load of the shaft, which works upon the journal to break it, is greater than the torsion, it is sufficient to take the measure resulting from it, including friction; the torsion may then be neglected. These rules apply particularly to water and fly-wheel shafts.

A practical formula to determine the size of a journal for cast-iron shafts, is to take twice the weight of the shaft, including wheels and all it has to carry; express this weight in cwts., extract the third root, and the resulting number is the diameter of the shaft in inches. The general formula is then, if P is the whole weight of the shaft, load and all, the diameter in inches is $d = \sqrt[3]{2 \times P.}$ If the load is distributed over the whole beam, or in the middle of the shaft, every journal has half the load to carry, and the formula applies to these cases. If, however, the load is all on one end, or near one journal, it is to be taken as half as much more than in the above formula. This rule applies to good cast-iron; if the shaft is of wrought-iron, and heavy, it may be multiplied by $\frac{10}{14}$; and if but light shafts are needed, the wrought-iron may be still diminished by multiplying it with $\frac{8}{14}$. In all cases, it is

advisable to take the shaft as stronger than this formula indicates. In case the load is on one end of the shaft, or a prolongation of the shaft at one end is to transmit the whole force of torsion, as is frequently the case in water-wheels, the journal which is to bear this may be made stronger, if it is an object to save metal and friction. If a shaft is loaded with a wheel of 60 cwt., and if that wheel is one foot from one journal and three feet from the other, then the first journal is to carry 45 cwt., and the other but 15 cwt.; the journals may be 4·4 and 3 inches respectively. The length of a journal bears no relation to its strength; this is a matter that is regulated by economy and practice. A journal should be at least as long as its diameter, if it has no load to carry; but if the shaft is heavy, the length should be at least one and a quarter or one and a half times that of the diameter. For the sake of lubrication, the length of the journal may be extended to two diameters, without loss of power. In this case the nominal friction increases slightly; but the advantages in lubricating more than counterbalance this trifling loss of power.

If a shaft is to transmit power in addition to carrying a load, the size is influenced by it, if the load is not greatly superior to the force of torsion. The diameter of a cast-iron shaft which is to transmit a certain horse-power, H, is to be multiplied by 400, and divided by the number of revolutions of the shaft per minute, n; then extract the third root of the quotient, which gives the diameter in inches. The formula is $\sqrt[3]{\frac{400 \times H}{n}}$. It is evident that in a factory, where many machines are at work, and where power has been derived from extended shafts, the strength of the shaft can be diminished in proportion. In all cases, it is advisable to add to each of the formulæ; it may be cal-

culated simply for torsion or for weight, as the losses in each case are only in friction and first cost.

The section of a shaft is commonly increased to that of the journals, for which there is no necessity, particularly if the shaft has no extra burden, such as straps, &c., to carry. If the length of the shaft is not beyond twelve diameters of the journal, a cylindrical form is quite strong enough; but if the shaft is longer, it is advisable to consider its weight and load, and especially its vibration.

If the size of a first shaft is determined, and this is to drive a second, third, and fourth, or series of shafts, by means of wheels or straps; then this series of shafts must be in proportion to the power they are to carry. The sizes or diameters of shafts are as the cubes of the diameters to the effects; that is, the number of revolutions per minute, multiplied by the power which the shaft is to transmit, is to its diameter as the cube of that diameter.

CHAPTER IV.

LAWS OF MOTION.—MECHANICS OF RIGID MATTER.

CAUSE OF MOTION.

WHEN a body is in motion, or is inclined to motion, there must be a cause for that impulse. Whatever this cause of motion may be, we call it *force*. In most cases we do not know the first source of force; we cannot even trace it to its origin; but in all cases we know the effects of a force, and the laws by which it is regulated. The quality of force is manifested in its moving matter with

more or less speed; or by one body pressing against another, which resists the impetus of the body in motion, with a certain pressure. In reality, we do not know, in most instances at least, what the force or forces are; we see their *effects*, however, and call these effects *forces*. We generally understand a force in mechanics to be a cause of motion; yet the sum of the effects of two such causes of motion may be rest, or may be more or less than one of the effects of the causes, as has been demonstrated in the parallelogram of forces. Motion is but a change of place; and a body in motion will move exactly to that place, when impelled by a number of causes acting together, as if each cause operated singly, or as if all of them acted alternately. Each cause of force expresses, in all instances, all the effect which belonged to it. For these reasons, we have to demonstrate force to be the effect of a cause; and the influence exerted by a second cause over the first cause, is not exerted over the *action* of the first cause, or the cause itself, but is exerted over the *effect* of the first cause, after that effect is completed, and manifested in force. For all our purposes, if we predict, calculate, or explain a joint result of causes, their compound results may be treated as if each of them produced, simultaneously, its own effect, and all these effects co-existed visibly.

LAW OF INERTIA.

If a body is at rest, it cannot move without a moving cause; at least we cannot perceive motion without a cause. A body once in motion cannot come to rest without a cause; if no force equal to that which moves it interferes with its motion, we cannot perceive how that body can be at rest. The law according to which bodies remain in their

previous condition, is called the "law of inertia," or the "moment of inertia." This law determines with what force a body continues at rest, or continues in motion.

VARIETIES OF MOTION.

The direction of motion can be either that of translation, or progression in a straight line; or one of rotation, or revolution around an axis. It may also be a compound motion, or a motion about a moving axis; the latter is a compound of the two. The speed of motion may be uniform; that is, a body may move through equal spaces in equal times; or it may be variable, and spaces and time may be in more or less distant relations. The latter kind of motion is accelerated when the spaces described in equal times are continually increasing at a greater ratio than the times; and a motion is retarded, when the spaces decrease in a greater ratio than the times. Motion may also be periodic; that is, when spaces and times are in a certain ratio at certain intervals only.

UNIFORM MOTION.

Velocity is the magnitude of motion. In this case the velocity is invariable; the measure for it is the path or space a body describes at any determined point of time. The time, as generally agreed upon, is one second, or one minute, one hour, day, month, or year. If the velocity, or measure of velocity, is simply stated, it means the path described in one second. The spaces described by one or more uniform velocities, in which the spaces are proportional to the times, are always uniform.

VARIABLE MOTION.

A motion is uniformly variable when its velocity either increases or diminishes in a certain time, and the ratio existing between both spaces and times is regular. The falling body, or gravitation, is uniformly accelerated in the vacuum, but is not so in the atmospheric air; it would be uniformly retarded in the latter, if the air was of uniform density. Gravity moves a body 16·11 feet in the first second of its descent; and if we substitute for that measure the letter $\frac{g}{2}$, the descent, or spaces, of a falling body in a number of seconds, if we take the times as units, is as the numbers 1, 3, 5, 7, 9, &c. The velocities are as the square of times or numbers 1, 4, 9, 16, &c. The general formula for the latter is therefore $V = \sqrt{2 \times g \times h}$, in which h is the height from which the body falls.

If no disturbing cause, such as the resistance of the air, acts upon an ascending body, the body will reach that height, and in the same time, to which the impulse received by the propelling force, converted into velocity, will raise it; or, in other words, a body must be propelled with the same velocity, to reach a certain height, as if the propelling force was the result of a free descent from that height. From this it follows that as much time is required for a body to ascend as to descend, provided there are no other forces acting upon it than gravity alone can exert. If a body is propelled in an angle to the vertical, the curve described by its ascent and descent is a parabola. The distance to which a body thus propelled will move in a horizontal direction, is as the sinus of the angles of deviation. The greatest distance to which a body thus thrown may be propelled, is under an angle of 45°. If a body is pro-

pelled under this angle, the horizontal distance will be four times its greatest height, and twice as far as the vertical height to which the same force would have moved it. When a body under the influence of gravitation is propelled horizontally, it will describe a parabola; and if the force by which it is moved is equal to the velocity belonging to its height above the horizon, the distance to which it is thrown is equal to its height. The laws governing these cases are complicated, and belong to the higher mathematics. It is, however, worthy of remark, that, in practice, the curves described by the fall of bodies, such as the flowing out of water from apertures, deviates considerably from the parabola, in consequence of the resistance of the air.

MOMENT OF INERTIA.

If a body is in motion, and we take the sum of its mass and velocity, we form the momentum. For a body moving in a straight line, we find the momentum by simply multiplying speed with mass, and calculate upon uniformity in these cases. We may call these laws also the measure of forces. From the above it follows that the momentum increases equally with the masses; and if the masses are equal, the increase is as the velocities, the latter being always considered in infinitely small times. Mass means that measure of force expressed by gravity, if it is not particularly expressed by other names. If a body is in an accelerated motion, the force required to keep it in motion is inversely as its mass; or the effect of a force is equal to the mass multiplied by the accelerating force. The accelerated force of a mass is as the space through which it has been moved, multiplied by the mass. The moving forces of two masses are, therefore, as these masses multiplied by their velocities, obtained in equal times; or they

are as the squares of the speed, resulting from equal spaces or distances, multiplied by the masses.

The momentum is the mass and velocity; if, therefore, a mass is equal to two, and is to perform the effect of four, it is to have a speed of two. If a pile-driver is only 10 cwt., and is to perform the service of one of 25 cwt., it is to have two and a half times the velocity of the latter; if the latter drops from a height of only five feet, the first is to be raised thirty-one feet to have the same effect, provided the air is not taken into the calculation. The first drop is two and a half times less than the latter; it must therefore fall two and a half times longer, or from a two and a half times two and a half higher elevation, and $2\frac{1}{2} \times 2\frac{1}{2} \times 5 = 31\frac{1}{4}$.

The effect of a force resulting from the combined efforts of velocity and mass, is as the mass multiplied by the velocity. A body, falling one second, arrives, at the end of that second, at its destination, with a velocity of 32 feet; and if that body weighs 50 pounds, its momentum will be equal $32 \times 50 = 1600$ pounds; with that weight it will press upon the matter which it touches.

FALL ON AN INCLINED PLANE.

If a body rolls or glides down an inclined plane, and we neglect friction and other impediments to motion, the velocity with which that body moves upon the plane is, to the velocity of the vertical free descent, as the length of the inclined plane to its height. The spaces of the moving body are consequently as the squares of the times, and the times as the velocities. The vertical motion of a rolling body on an inclined plane is as the length of the plane to its height. The time in which a body glides or rolls down an inclined plane, is to the free descent as the height of

the plane to its length. The velocity of a body on the inclined plane is equal to that velocity by which the body would descend if moving free; and it arrives at the end of the plane with the velocity with which it would arrive, if it descended freely from the same height.

MOTION AROUND AN AXIS.

If a mass moves around an axis, the moment of inertia, or the moment of rotation, is equal to the squares of the distances from the axis of revolution. If the axis of a revolving body is not in the centre of its motion, it will move around an imaginary axis, which is parallel to the first, and passes through the centre of gravity; the momentum is then as the mass of the body, and the square of the distance of the two axes. The whole mass of a body may be supposed to be concentrated in one point, the centre of gravity; and its distance from the axis around which it moves may be determined by the supposition, that the mass so concentrated possesses the same moment of inertia, as if that mass were distributed over the whole space which it encloses in its motion. The calculations belonging to this subject are beyond our limits, however interesting they may be; they ought to be studied by the engineer, to assist him in determining accelerated motions.

CENTRIFUGAL FORCE.

When a body or mass is moved in a circle or curve around an axis, it has in every point of its path an accelerated motion, deviating from the direction of its motion. If we fasten a body to a string, and fling it round, it will stretch the string with a force which is to the mass as twice the free descent belonging to the velocity of the mass is to

the radius. Or, if V is the centrifugal force, M the mass, C the velocity, and r the radius; then

$$V : M :: 2 \times \frac{C^2}{4 \times \frac{g}{2}} : r.$$

From this it follows that the mass, multiplied by $\frac{C^2}{g \times r}$, is the centrifugal force.

If a body moves in a circle around an axis, and T is the time for one revolution, π the number 3·14159; then is $2 \times \pi \times r = T$, and $C^2 = \frac{4 \times \pi^2 \times r^2}{T^2}$, and $V = \frac{4 \times \pi^2 \times r^2}{2 \times g \times r \times T^2} \times M = \frac{2 \times \pi^2 \times r}{g \times T^2} \times M.$

A body, say a leaden ball, weighing six ounces, and fastened to a string of two feet long, is swung in a circle with a velocity of five feet per second; the centrifugal force, or the tension on the string, is then, if $V = 4 \times \frac{\frac{2 \times C^2}{g}}{2} \times r \times M$, as shown above, $V = \frac{5^2 \times 6 \times 2}{2 \times 32 \times 2} = 2\frac{11}{32}$ ounces. If the string is only one foot long, then is $V = \frac{2 \times 5^2 \times 6}{2 \times 32} = 4\frac{23}{32}$ ounces. If the speed is increased to $5\frac{1}{2}$ feet per second, then $V = \frac{2 \times 5{\cdot}5^2 \times 6}{2 \times 32} = 5\frac{21}{32}$ ounces, or nearly equal to gravity. If, in the latter case, the ball is swung round horizontally, it will describe a plane at an angle of 45° with its string, because the gravity is then equal to the centrifugal force.

The centrifugal force increases, therefore, as the square

of the velocity; and as this, in circular motions, is dependent upon the number of revolutions, as the square of the number of revolutions, and simply as the diameter. If, therefore, we want a great centrifugal force, it is better to increase the speed than the diameter.

If a number of bodies revolve about a common axis, and at various distances, then we have to find the common centre of gravity for all these forces. Through this centre of gravity passes the centrifugal force; and it is exactly as if all these forces were collected in that centre of gravity. The centrifugal force is calculated for that centre.

PENDULUM.

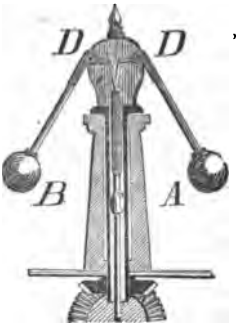
A weight suspended on a movable axis will vibrate, if once set in motion; if that motion is caused by gravity, then the times in which it will perform one vibration are as the square roots of the length of the pendulum, calculated from the centre of the axis of suspension to the centre of gravity. If the pendulum is a string, and the weight suspended a leaden ball, the centre of gravity is nearly in the centre of the ball. The number of vibrations in a certain period of time, say one second, is inversely as the square roots of the length. A pendulum which is to perform one vibration in one second, must be $39\frac{1}{8}$ inches. If a pendulum is to make 75 vibrations in one minute, it is to be 25 inches long. It is here $\sqrt{39\frac{1}{8}} : \sqrt{x} :: 75 : 60 = 39\frac{1}{8} : x :: 75^2 : 60^2 = \frac{140850}{75 \times 75} = \frac{140850}{5623} = 25.$

GOVERNOR.

The pendulum commonly used in connection with steam-engines and water-wheels, for regulating the speed of these first movers, is not subject to the laws of the common pen-

dulum; it is calculated by the rules of centrifugal force. If two balls, fig. 40, A B, are suspended on two movable rods, and swung round by the vertical central shaft or axis, C, the balls will recede from the axis, and describe circles around it. If the weight of each of the balls is 50 pounds, and the centre of gravity is assumed to be in the centre of the balls; and if we neglect the resistance to the upward motion of the balls by the rod C; and if the arms from the centres D to the centre of the balls are two feet; the governor is to make thirty-eight revolutions in a minute, to raise the balls to an angle of 45° with the rod C, or their point of suspension. As shown above, the centrifugal force is equal to gravity, if it is $= \frac{C^2}{g \times r}$, which is in this case $= \frac{C^2}{32 \times 2}$, $C = \sqrt{32 \times 2} = 8$. This requires a speed of eight feet for the balls, in revolving around the vertical axis with a diameter of four feet. But as the diameter at the balls is not four feet, we are to substitute the real radius in the above formula; it is then, $\frac{C^2}{32 \times \sqrt{2}} C = 6{\cdot}6$.

Fig. 40



IMPACT — CONCUSSION.

If two bodies come in contact with each other, so that one strives to penetrate or occupy the space occupied by the other, a reciprocal action takes place, which produces a change in the condition of the bodies so coming in contact. The effect of forces acting thus upon two or more bodies, is shown in action and re-action. The first effect

of contact is a change in the form or volume of the bodies, which begins at the point of contact, and diffuses itself further through the mass. By this inward change of the body, the inherent elasticity is called into action, and puts itself into opposition to the acting force, and, if strong enough, into equilibrium. Action and reaction are here, if the body is absolutely non-elastic, equally and simultaneously opposed to each other. All matter, however, is elastic; and for this reason a certain time elapses before reaction takes place. The degree of elasticity is measured by the time which is thus occupied. Perfectly elastic bodies, such as ivory, steel, and water, recover their perfect form after concussion takes place; but if, after the moment of impact, a lasting impression remains, the body is imperfectly elastic. In practice, there is no absolutely non-elastic matter, nor is there any which is absolutely elastic; but the laws governing this case are more readily understood if we assume such matter. If two bodies, neither of which is elastic, meet in a straight line, both having the same mass and momentum, no motion can result from their contact; all the force of the two bodies is, at the precise time of contact, annihilated. In this instance there can be no reaction; for, as the form of the bodies cannot be altered, there is no tendency on their part to lose or resume their form, and consequently there cannot be reaction — the only cause of motion in this instance. If one non-elastic mass is larger than the other, and they meet in the direction of their centres, a part of the force of the stronger is lost, and that of the smaller is annihilated; the latter absorbs a portion of the force of the larger mass, and both move with reduced speed in the direction of the stronger. If two non-elastic bodies are moving in the same direction, but with different velocities,

and one body overtakes the other, the force and velocity of both is the sum of the forces in both. If a large mass is at rest, and a small mass in motion touches it, it will move; but its motion will be at a reduced speed to that of the moving body. If a body weighing one pound moves with a velocity of ten feet, and touches in its course a resting mass of 1200 pounds, both will move with a velocity of $V = \frac{10 \times 1}{1 + 1200} = \frac{10}{1201}$, or nearly one-tenth of an inch. In the contact of two absolutely non-elastic bodies, which meet when both are in motion, there is an actual loss of force; what becomes of the force thus lost, we do not know. In practice, as we have already said, no such bodies are to be found; this is a principle to be remembered by the engineer.

If two perfectly elastic bodies meet in the line of their centres, they will recoil from each other with the same force, and, if of different speed, return with exchanged velocities. In this case, reaction is exactly as strong as action; the impression made on each mass will, in recovering, recoil upon the other mass, and impart to it its own speed. If, therefore, an elastic mass in action touches another elastic mass at rest, the first will impart all its force to the latter, and be at rest, while the latter moves on with the velocity of the first.

These laws are of the utmost importance in practice. By the impact of elastic bodies, no power is lost; but in the concussion of absolutely hard matter, some power is lost in all cases, and in many instances all the force is annihilated. If, in pile-driving, the ram as well as the pile were made of absolutely hard matter, the strongest force applied to the ram, or drop, would not move the pile; while, when the drop and pile are elastic, all the force of

the drop is imparted to the pile. If, in the attempt to break a body, the matter to which the force is applied, as well as the matter to be broken, are both elastic, the work will proceed but slowly; but if both the hammer and the body to be broken are absolutely hard, either both will fly in pieces, or no effect will be produced.

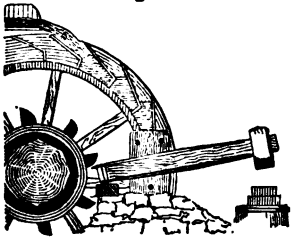
HARDNESS.

All matter is more or less elastic, and the degree of that elasticity we generally denominate hardness. From the foregoing it is evident that the impression made by one body upon another must be inversely proportioned to its hardness. This leads us to the consideration of the modulus of elasticity, or the degree of impression made by a force in compressing or bending matter. This subject, so far as it is of interest to us, has been discussed in a previous portion of our work.

ROTARY BODIES.

If two bodies, such as cog-wheels, revolve around their axes, and strike against each other, the laws above developed are applied, with due regard to rotary motion. The moment of inertia is the measure of force, and the hardness of the striking bodies is the rule by which the effect of one wheel upon the other is determined. If the striking point moves, and that which is struck is at rest, as is the case with tilt-hammers, the law of inertia is applied, as before. In all these cases, the degree of elasticity of both bodies requires to be considered. If the shaft, cam-ring, and tup-

Fig. 41.



pets, on a tilt-hammer, (fig. 41,) are of absolutely hard material, they will inevitably break in attempting to lift the hammer. If the hammer-helve and housings were non-elastic, they also would break. The whole force of the moving power will be expended in breaking the machinery. If, on the contrary, the parts of the machinery are elastic, all the force of the first mover will be imparted to the hammer. On this account, we frequently see cast-iron rejected in the construction of such machinery, and wood, from its greater elasticity, preferred to it. The same reasons which induce the erection of wooden tilt-hammers, act in the construction of stamping-mills and crushing apparatus. If the material of which such machines are built is to a certain degree elastic, the machine will be more durable, and the power of the first mover will be more perfectly imparted to the matter upon which it acts.

CENTRE OF PERCUSSION.

If a body turning about a fixed axis is moved by a force, a reaction of the blow imparted will take place upon the axis of the body. The force of that reaction is dependent upon the distance and direction of the impact, and that of the axis. In most cases, the direction of the blow is perpendicular upon the axis of revolution; such is the case in the common hammer; it also passes through the centre of gravity. If we assume the latter case, every blow passes through the point of gravity, and is completely taken up by the mass, without having any effect upon the axis, or producing any pressure. Hence we do not feel, on the wrist, the reaction of a blow by the common hammer with a wooden helve, because the point of gravity and the centre of percussion fall in the same place, or at least in the direction of the blow, which is the same thing. If the

centres of percussion and gravity do not fall in the same line or plane, or that line which is vertical upon the axis, the reaction is more or less felt according to the deviation from it; and as the wrist of the hand is the axis to the hammer, the blow reacts upon the wrist. In striking with a rod of iron upon a sharp edge, or the corner of an anvil, we perceive a strong reaction upon the wrist, if we strike the bar in or below its point of gravity. In this case, as in every other of a similar kind, we have to consider the rotary motion performed by the hand, which, in all cases of a prismatic bar held at one end, throws the centre of percussion two-thirds of the length of the bar from the axis. If, therefore, we strike the bar in any other point than two-thirds of the length from the hand, we perceive the reaction, and in that point only; the whole force of the blow is absorbed by the bar, without the slightest reaction upon the axis of motion. This subject should be carefully considered in the construction of machinery on which it has an influence.

FRICTION.

The chief impediment to motion is friction. We distinguish two kinds of friction; the one forming the resistance to the sliding of one body upon another, and the other the resistance to the rolling of a body upon another. The laws which regulate friction are the following: Friction does not increase or diminish with the speed of the sliding body; it is not increased with the sliding surfaces, and is proportional to the pressure of the bodies. The latter law cannot be applied generally; for it changes in some measure with the quality and variety of the sliding materials, and their surfaces. Besides the above rules, we distinguish between friction in motion, and friction at rest. If the

body is in motion, the friction is less than when the body has been for some time at rest, and is then to be moved. In the Appendix we furnish two tables, one with friction at rest, and the other in motion.

Where unguents are used between two rubbing surfaces, a difference in the amount of friction is apparent. If the pressure be great in proportion to the surfaces, the unguents will be pressed out, and the materials rub upon one another, being brought into intimate contact. As long as either of the two states of things is in existence — that is, as long as any lubricator or none at all is between the surfaces — the laws of friction are unaltered; but in the intermediate state, or where the lubrication is insufficient, the laws do not apply. That law which relates to the rubbing surfaces is, in practice, modified in regard to lubrication; for if the surfaces are too small, all the unctuous matter may be pressed out, and the rules are then altered.

The laws of friction are very simple in their nature and application; still, there is not as much attention paid to this subject as it deserves. With a view to familiarize our readers to the operation of these rules, we annex a series of applications.

A sliding water-gate is made of oak, and its centre is five feet below water; the gate is three feet wide and three feet high, and made of two-inch plank. How much force is required to lift the gate?

The weight of the gate is equal to one and a half cubic feet of oak wood; and as it is assumed to be always submerged in water, its weight may be ignored, as it is nearly equal to the displaced water. The pressure of the water upon its centre is $60 \times 5 \times 3 \times 3 = 2700$ pounds; it is the height of pressure multiplied by the surface of the gate in feet, times the weight of one cubic foot of

water. The friction of oak upon oak, as shown in Table I., is ·71; this, multiplied by 2700, gives 1917 pounds; and to this is to be added the weight of the gate, which makes 2017 pounds as the force required to move the gate, when at rest. The weight of the gate, from its being below water, is not generally taken into account; for the weight of the wood is nearly balanced by the water displaced; but in practice it is found that the parts above water, and the iron at the gate, are equal to the weight of the gate below water. This subject is merely put in the calculation to draw attention to it.

If the gate is once in motion, not so much force is required to lift it; according to Table II., the friction of oak upon oak in motion is ·25; this will reduce the number to $2700 \times \cdot 25 = 650$ pounds, to which is to be added the weight of that portion of the gate which is above water.

A cast-iron gate dips two feet in water, and is four feet long; the weight of the iron gate is balanced by counter weights; the friction of the gate only, therefore, is to be considered. The pressure of water upon the gate is 4×60, if 60 is the weight of one cubic foot of water. By referring to Table I., we find the coefficient for cast-iron to be ·314. The force required to lift the gate is therefore $4 \times 60 \times \cdot 314 = 75$ pounds.

If a cast-iron saw-frame, weighing 200 pounds, moves upon rods made of bronze, and greased; how much force is required to move that frame?

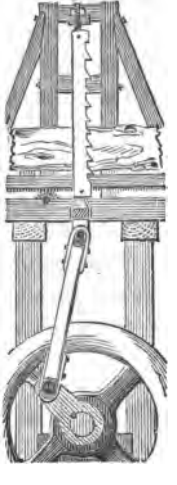
The friction of cast-iron upon bronze is, according to Table II., ·07; this, multiplied by the weight, makes the force necessary for motion $200 \times \cdot 07 = 14$ pounds.

LOSS OF POWER BY FRICTION.

The amount of power which is consumed by friction, is equal to the friction itself, multiplied by the velocity. The velocity here is the speed with which two surfaces glide over each other. Where but one surface is in motion, the velocity of that surface is the measure; but if both surfaces are in motion in opposite directions, the sum of the two velocities is the measure. If both surfaces move in the same direction, then the difference of speed is the measure.

If the length of stroke in a saw-frame is 18 inches, and, as in the above case, cast-iron runs upon bronze, and the pressure of the frame upon its bearings is 200 pounds, it causes 14 pounds friction; if the saw-frame makes 100 strokes per minute, the space through which the frame travels in that time is $100 \times 2 \times 1{\cdot}5 = 300$ feet; the loss in power for one second is therefore $\frac{300 \times 14}{60} = 70$ pounds lifted one foot high, or 4200 pounds lifted one foot in a minute.

Fig. 42.



If a saw-mill (fig. 42) is furnished with a fly-wheel or water-wheel, and the weight of the wheel, shaft, crank, pitman, saw and frame, and the resistance of the saw in the wood, are equal to 2000 pounds; and if the crank-shaft is of wrought-iron, the pans of brass or bronze, and the lubrication under water; we find, by referring to Table III., that the friction will be ·19. If the journals are four inches in diameter, and make 100 revolutions per minute, they will describe a way of $4 \times 3{\cdot}14 \times 100 = 1256$ inches in that time. The whole

weight is 2000 pounds, and friction is ·19; this makes 380 pounds friction carried through 104·5 feet every minute, or 40,720 pounds one foot high. This represents the power required to move the saw-frame and saw-log with it. In reality this amount of power is not required for a single saw; the weight and resistance are here fictitious numbers, applying to three blades in one frame.

A water-wheel weighs 20,000 pounds, including all the weight resting upon the journals; iron, wood, and water. The shaft of the wheel may be of cast-iron, and its journals 12 inches in diameter, running in brass or bronze pans, the wheel making six revolutions per minute. By referring to Table III., we find the friction to be ·16, because water is always on these journals. This makes the loss of power in this water-wheel $20{,}000 \times \cdot19 \times (1 \times 3\cdot14) \times 6 = 61{,}592$ pounds lifted one foot high; and if 33,000 pounds lifted one foot high is equal to one horse-power, the wheel will lose $\frac{61{,}592}{33{,}000} = 1\cdot8$ horse-powers, by friction.

The friction in a step for a vertical shaft is taken from Table II. If a vertical shaft, with all its appendages, or the whole weight resting upon the pivot, is 6000 pounds, and the diameter of the pivot is six inches; the latter made of cast-iron, and running in a brass or bronze step with twenty revolutions per minute; what is the loss in friction?

The speed belonging to the pivot is that which belongs to the periphery of half the surface; it is here

$$3\cdot14 \times 2 \times \frac{\sqrt{\frac{6^2}{4} \times 3\cdot14}}{2 \times 3\cdot14} = 14\cdot1 \text{ inches,}$$

or $1\frac{1}{6}$ foot, multiplied by the number of revolutions, which makes it $20 \times 1\frac{1}{6} = 23\frac{1}{3}$ feet. We have now $6000 \times \cdot 15 \times 23\frac{1}{3} = 21{,}000$ pounds one foot high.

In calculating the weight of shafts, either vertical or horizontal, the forces which increase the weight are to be added to it, and those which diminish it are to be subtracted. If on a horizontal shaft there are one or more straps, which pull the shaft with a certain force downward, that force is converted into weight, and added to the weight of the shaft. If the direction of the pulling force is not vertical, it is calculated according to the angle of deviation from the vertical. A strap pulling directly upward is subtracted from the total weight of the pressure with which a shaft rests upon its bearing. Horizontal straps add only half their own weight to the weight of the shaft. In calculating the weight of a water-wheel, we add only half the weight of water to the overshot wheel, because half its weight is spent in its motion with the wheel. Undershot wheels receive no addition to their weight by the driving force; on the contrary, their weight is generally diminished by it.

The pressure upon shafts caused by cog-wheels is generally not very large; still, it is to be counted, particularly where the cogs are imperfectly constructed, and cause friction in their contact. All the forces acting upon shafts must be either vertical or horizontal; if not so, they must be converted into one or the other; and the vertical is the most convenient. The law of the parallelogram of forces will afford the means. It is readily understood that where the pressures upon two shafts, connected by gearing, bear one upon the other, each shaft must be calculated by itself.

In practice, the amount of friction depends in a great measure on the condition in which the surfaces may be,

and also on the kind of material of which they are made. The friction is least where the surfaces are of the most perfect geometrical form, that is, either straight or round, and the more smooth and highly polished they may be. Rough and uneven surfaces cause a great deal more friction than those calculated in the tables, in which the most perfect forms are supposed to work upon one another. Friction is greatly diminished by lubrication, and particularly by a permanent lubricator. The best unctuous matter for these purposes is fat oil, grease, washed plumbago, or similar material. Water, in all cases, increases the friction, and, if it can be prevented from coming in contact with sliding surfaces, it is advisable to do so. In many cases, however, it cannot be dispensed with; such as in rolling-mills, upon the gudgeons of rollers, or where the journals, in consequence of their too small surfaces, become heated by pressing out the unguent matter. The smaller the surfaces in proportion to their weight, the harder the lubricating matter is to be, though this always increases friction. It is therefore bad policy to make surfaces too small. Journals may be increased in length without increasing friction; but their diameter ought to be as small as possible. The quality of unguent matter is the most favourable, if it is in a liquid state between the two surfaces, such as oil; but if the journal becomes heated in its motion, the fluid oil will flow out, and leave the rubbing surfaces dry. In these cases, fat or grease must be used, because these substances melt by the heat of the metal, and may be retained between the surfaces.

The friction between homogeneous matter is, under the same conditions, greater than between heterogeneous matter; the working of wrought-iron upon wrought-iron, therefore, and also of cast-iron upon cast-iron, ought to be avoided.

Friction arrives at its highest value in the shortest time when metal runs upon metal, when motion ceases, or lubrication is destroyed. Metal upon wood takes a longer time of rest before the highest degree of friction is obtained; and wood upon wood frequently requires some days of rest before the same effect is produced.

Friction between fibrous matter diminishes with the increase of pressure. The friction between two hemp belts or ropes may be more than one pound, if the pressure is but one pound; if the pressure is increased to 60 pounds, the friction between the same matter may be but 20 pounds. The friction is less between coarse stuff, or rough surfaces, than between fine stuff, or smooth surfaces. In all these cases, the friction increases with the time the two bodies are in contact and at rest. The friction between ice and other matter decreases considerably with the increase of weight. The friction between leather and other matter increases more rapidly than the pressure.

The measure of friction is frequently determined by the angle assumed by the inclined plane upon which the sliding body is at rest; that inclination at which the body begins to move is called the angle of friction. This angle, for stone, is from 28° to 30°; and this ought to be the line of equilibrium in joints of arches.

ROLLING FRICTION

Increases with the surface; two cylinders, turning about their axes, and moving upon one another, cause but very little friction. This subject, however, is not yet brought under general laws, and is to be more definitely settled by observation in each particular case, before any rules can be given.

Sliding friction of ropes over pulleys, rafters, square

prisms, or polygons, is calculated by means of the same laws as other friction; the angles in the pulleys and corners over which the rope runs are, however, to be considered. The bending of ropes, chains and straps, are practical instances, to be considered in each particular case.

CHAPTER V.

LAWS OF REST IN FLUIDS AND GASES.

PERFECTLY FLUID MATTER

YIELDS to the slightest effort exerted to change the relative position of the particles, and they move freely among each other in all directions. When particles adhere more or less together, the fluid is imperfect; if they are so large as to be visible, as is the case with sand, the aggregation of such particles is called semi-fluid. We shall speak chiefly of perfectly fluid and perfectly elastic matter; these qualities are combined in all matter; a fluid, compressed, will always assume its former volume when the pressure is removed. The amount of change of volume in compressed liquids, under equal pressure, is different for different fluids. In liquids, the amount of compression is so small, that we can neglect it altogether in our investigations. The compressibility of gases, or aeriform bodies, is very great. For our purposes, we treat chiefly upon water and atmospheric air

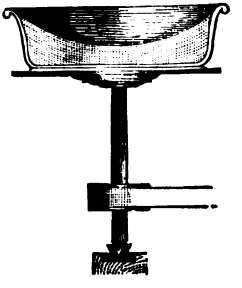
EQUALITY OF PRESSURE

Is the most characteristic property of fluids; they transmit the pressure which is exerted upon the surface, or part of the surface, of the fluid, in all directions unchanged, without loss of power. The pressure on solids is transmitted in one direction only. Gravity causes all particles of water to move in the direction of that force; and they would actually move to the centre of gravity of the earth, and aggregate around it, if water was not prevented by solid matter from doing so. Water will therefore form into round globules in all instances, if no other cause but its own cohesion acts upon it. The surface of the earth is the surface of a globe, which we call level; and if no other causes act but gravity and cohesion, water will be always at a level. If all the water is at a level on the surface of the earth, a part of it will be at a level in any vessel in which it may be contained.

OTHER FORCES THAN GRAVITY,

Acting upon water, will always be perpendicular upon the particles; or, what is the same, the particles of the fluid will be perpendicular upon the combined forces of gravity and others. If water in a round vessel is made to revolve about its axis, (fig. 43,) the water will rise at the sides of the vessel, the lower portions of the fluid will press the higher upward at the periphery, and the surface of the water will form a curve. The rotary motion causes

Fig. 43.

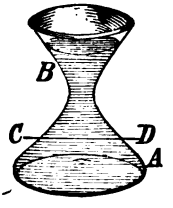


the centrifugal force to drive down the centre of the water. The curve thus described by the centre of the fluid is a parabola, whose axis is the axis of revolution.

THE PRESSURE ON THE BOTTOM OF A VESSEL,

By the supernatant fluid mass, is equal to the surface multiplied by the height. If we divide the water in a vessel into a certain number of level strata, the first or upper stratum will press with one stratum, the second with 1 + 1, the third with 2 + 1, the fourth with 3 + 1, and so on to the lowest, which is pressed with all the strata. It does not make any difference which way the sides are sloped; the pressure upon the bottom is always the same. If, in fig. 44, representing a vessel filled with water, the fluid in A is pressed by a force passing through the narrow part, and that force is equal to the whole height of the column of fluid; it presses with equal force upon the bottom and sides of the vessel. The pressure upon liquids is, throughout the body of the liquid, the same; consequently, the pressure is everywhere the same; and as gravity is the only force coming into action in this case, the bottom will be pressed with all its power. The stratum of water in CD is pressed from above, but equally as well from below. A characteristic of water is, that when a stratum is pressed from below, it will press with the force belonging to it against the sides of the vessel, in an opposite direction to gravity. The pressure of water against any plane surface is equal to the weight of a column of water whose base is that surface, and whose height is the head of water. It does not make any difference in the pressure upon the sides of a vessel which con-

Fig. 44.



tains water, whether that water comes from a small pipe, and is just sufficient to fill the vessel; or whether the force of a whole lake is applied. The pressure is the same, so long as no motion is perceptible.

LEVEL OF WATER IN PIPES.

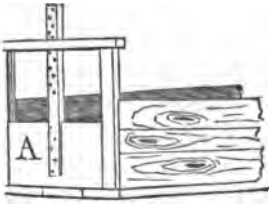
If a pipe is bent in the form of a syphon, fig. 45, with one end of it very wide in proportion to the other, the water will be at equal heights in both pipes, provided they are vertical. The nature of fluids, as defined in the commencement of this chapter, requires the two surfaces in unequal sized vessels, which are in communication, to assume the same level.

Fig. 45.

HORIZONTAL PRESSURE.

If a square vessel with vertical sides is filled with water, the pressure against the vessel's sides is equal to the weight of a column of water whose base is the surface, and whose height is the head of water upon that surface. If the gate A, fig. 46, is four feet wide and two feet high, it is the basis of a column of water of one foot high; the pressure against it is then $\frac{2 \times 4}{2} = 4$; these are cubic feet, which are to be multiplied by the weight of one cubic foot of water, and the result shows the pressure in pounds. If the height of the gate increases, or if the gate is higher than the water, and the water raises upon it, the pressure increases with the

Fig. 46.



square of that height; for in this case the height of pressure and surface both increase. The pressure increases simply as the width of the gate. It makes not the slightest difference in the pressure whether the gate is affixed to a small tub or to a lake, provided the water is at rest.

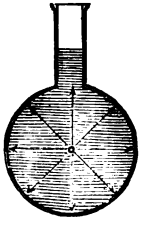
If water presses on both sides of a plane, vertical, or inclined surface; or if, for example, water was raised to a certain height on the opposite side of the gate A, fig. 46; the pressure on one side, subtracted from that on the other, would show the amount of pressure on one side of the gate.

Whatever may be the form of a curved surface of a vessel, the horizontal pressure is always equivalent to the weight of a column of water whose base is a vertical projection upon the surface. The vertical section of a vessel, which divides a vessel containing water into two equal or unequal parts, is the vertical projection of the two parts.

THICKNESS OF PIPES.

The laws of pressure caused by water are applied to find the thickness of water-pipes. If fig. 47 represents a pipe with a certain head of water, it is evident that the pressure against the circumference of the pipe is from the axis or centre of gravity in the direction of the arrows. It follows from this that the strength of a pipe should be as great — in practice it ought to be two or three times as great — as the head of water upon a unit of surface.

Fig. 47.



Or, if we transform these words, $C = \frac{RH}{K}$, wherein R is the radius, H a unit of surface, and K the modulus of elasticity; that is, that strength which resists a permanent alteration of form. C is the strength of the pipe. It

follows from this that a pipe three times as wide as another, which has five times its pressure to sustain, must have its sides fifteen times as thick. In practice, we have not only to consider the interior pressure which the pipe has to sustain, but also the weight which it has to carry, together with its own weight. If the interior pressure is far greater than the support of the pipe, the latter can be neglected altogether. In all practicable cases, it is advisable to try the strength of pipes by means of a force-pump.

BUOYANCY.

A body immersed in water, is pressed upon by the water on all sides. A body which is of exactly the same specific gravity as water, is at rest in every position and in every depth of water. If the whole or only a part of a body is submerged, the force by which it is lifted upward, or its buoyancy, is equal to the whole weight of water displaced by it, or a quantity of water of the same volume with the body submerged. If the specific gravity of the body is greater than that of the water, the body will sink in it; and if the specific gravity is less, a part of the body will be above the surface of the water. A floating body will be at rest, if its centre of gravity and the centre of gravity of the displaced water are in the same vertical line. This vertical line is the line of flotation. The plane which passes through the body, on a level with the surface of the water, is the plane of flotation. The depth of flotation may be calculated with ease, if we know the specific gravity of the floating body, and the specific gravity of the water in which it floats.

THE STABILITY OF A FLOATING BODY

Depends on the plane of symmetry drawn through the axis of flotation. A body floats with stability, if it maintains its state of equilibrium or rest. The stability is secured if its centre of gravity is supported; that is, if the vertical line drawn from that point passes through its base, or the plane of support. The stability of a floating vessel (fig. 48) depends upon the position of the two points A and B. If the point A, which may be the centre of gravity of the vessel, lies above the point B, which is the centre of gravity of the displaced water, the vessel will not float with stability; it will be restless, and inclined to upset. If the point A is below B, the vessel will float, with a tendency to regain its equilibrium if thrown out of it by any cause; it will float with stability. If the points A and B fall together, the equilibrium is indifferent; the vessel will be at rest in any position.

Fig. 48.

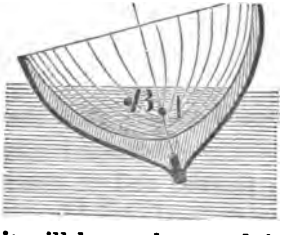
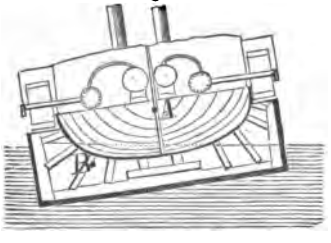


Fig. 49.



If a vessel is provided with a flat bottom, this law is in some measure modified, as may be more clearly shown if we illustrate it by the position of a floating dock (fig. 49). A floating dock is a square, flat-bottomed box, into which a boat or ship may be taken for repairs; the water is pumped out, and it will carry the ship, with all her rigging and machinery, above water. If

the centre of gravity, A, of the vessel — that is, of both vessels — is above the centre of floatation, B, any movement to one side will change the point B to the sinking side, and the point A will strive to restore equilibrium; but if A should be moved so far as to come on the other side of B, the dock with the vessel it contained would inevitably capsize. These are the reasons why flat-bottomed river boats may have the centre of gravity far above the centre of floatation, and be perfectly safe. In a sea or ocean, where high waves cause a considerable inclination of floating vessels, such an arrangement would not be considered safe.

It is not necessary to know the specific gravity of the body immersed, in order to calculate its buoyancy; it is sufficient to know its absolute weight; and that part of the form of the vessel immersed, will show the depth to which it will sink. The total weight of the vessel is exactly equal to the amount of water displaced. The centre of gravity of the vessel, however, must be ascertained, in order to calculate its capacity for stability.

DENSITIES OF WATER.

To determine the density of water and other fluids, areometers are used; but this subject does not properly belong to our treatise. When water of different densities is brought into contact, it mingles and assumes a uniform density. This, however, is not the case with all fluids. When fluids do not mingle, such as oil and water, or quicksilver and water, and two such fluids are in communicating tubes, the height of the liquid in each tube will be inversely as the specific gravity of the fluid. If the communicating

Fig. 50.

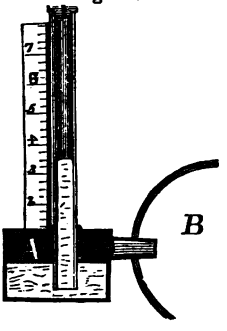
tube (fig. 50) is filled, in either one of the limbs, with one pound of water, and in the other limb one pound of quicksilver, the water level will be 13·6 times higher than the level of the quicksilver, before both fluids will assume a state of rest.

TENSION OF GASES.

This property of gases may be called their elasticity; it is that property which makes them expand, and exhibits itself in its pressure against the sides of a vessel in which it may be enclosed. This property distinguishes gases from liquid fluids; for the latter will expand to but a certain degree, while gases may expand to any extent without losing their inherent quality. Gases, at any degree of density, press in proportion to that density; fluids do not. The density of gases is measured by the barometer, the manometer, and often by a valve; the latter is used for steam-boilers and blast-machines. The barometer is a well-known instrument; its application does not fall within our province. The manometer is a useful instrument for measuring densities, and ought to be within the reach of every engineer who is engaged in machinery where gas or air is the motive power.

Manometers are frequently formed of two communicating glass tubes, where the quicksilver in one tube is driven down by the elastic gas, and raised in the other tube. Such a form of manometer is objectionable, because the scale affords only half the actual pressure; and if the amount of fluid is not always exactly the same, no permanent scale can be applied. The best form of a manometer is represented in fig. 51, where A is a square wooden box, containing mercury or any other fluid; this box may be made of iron, if high pressures are to be measured. At

Fig. 51.

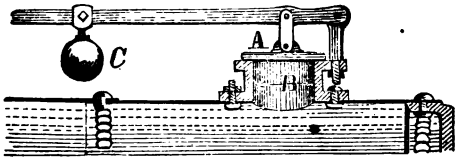


one end of the box is a short conical pipe, which, when screwed into another pipe containing dense air or gas, forms a communication between the pipe B and the box A. If there is no pressure in A, the mercury in the box and the inserted glass pipe will be at rest, and at a level; but as soon as the air is more dense in the box than out of it, it will attempt to escape through the glass pipe, and will press a part of the fluid from the box into the pipe. The height to which the fluid in the pipe is raised, is directly proportional to the density of the gas. This density is generally measured by inches in quicksilver, two inches in height of which are a little more than one pound to the square inch of surface exposed to the pressure of the gas. It is less trouble to measure and calculate in inches than in pounds. The measuring at the cistern manometer is, as in every other case, counted from the surface of the quicksilver in the box; and as this surface is generally very large in comparison with the width of the pipe, the difference in the height of the fluid in the box is usually neglected, and a permanent scale applied to the manometer.

VALVES.

Where manometers are unsafe, or cannot well be applied on account of high pressure or heat, as is the case at steam-boilers, the expansion is measured by a valve (fig. 52). This valve is generally used as a safety valve; it is less useful as an apparatus for measuring the density of steam or of gases. The valve A is liable to corrosion, and consequent adherence to its rest, for which reason it will in

Fig. 52.



many cases not indicate the actual density, but a higher degree. Densities below the adjusted pressure cannot be observed at all with this valve. The section of the passage B in inches, divided into the whole weight of the valve A, and the weight of the lever, the weight C and the leverage, show the density of the enclosed gas, in pounds, on one inch of surface. If B is 6 inches in diameter, the weight of A 20 pounds, and the weight of the lever 40 pounds; the point of gravitation being in the middle of the rod, the support from the fixed point resting on the valve to be one-fourth of the whole length, and the weight C to be 50 pounds; then the pressure necessary to raise the valve would be $\frac{20 + (40 \times 2) + (50 \times 4)}{3^2 \times 3{\cdot}1415} = 10{\cdot}6$ pounds on the square inch. If the valve is once opened, a smaller force than 10·6 pounds will keep it open; for the motion of the escaping gas will afford some force. Connected with the surface of the valve is a portion of the ring which covers the escape-pipe. As long as the valve is shut, that ring is dead; but as soon as the valve is opened, its surface increases in some proportion to the surface of the ring, and the density of the escaping gas between the valve and its bearing.

LAWS OF TENSION OF GASES.

The tension of gas increases with its density; the more a certain quantity of air is compressed, the greater is its

tension. The greater the rarefaction or expansion of gas or air, the less expansive force will it exhibit. The ratio in which density and expansive force are manifested is, that tension and density follow the same law. The density of the same quantity of air or gas is in proportion to its tension, or the pressure it exhibits; or the densities are inversely as the spaces occupied by the same gas. The volume is, therefore, inversely as the expansive force in the same body of gas. If a certain bulk of air is compressed by some means, and its compression is carried to one-half its original bulk, the pressure against the sides of the containing vessel will be twice as great as at first. If atmospheric air is compressed to half its volume, and the atmosphere is supposed to press upon the inch of vacuum with sixteen pounds, the air condensed to one-half will press upon the vacuum with thirty-two pounds to the square inch. If the same air be compressed to one-third of its former volume, the pressure upon the vacuum will be forty-eight pounds, or thirty-two pounds to the vacuum.

STRATA OF AIR OR GAS.

Atmospheric air, or any gas, enclosed in a vessel, is more dense in the lower strata, or those nearer to the surface of the earth, than the upper strata, or those farther from it. At the same height or distance from the centre of the earth, the stratum is always of the same density. The increased density in the lower strata is caused by gravity, and of course the greatest density will be at the centre of the earth. In this particular, gases are distinct from solids and fluids. The law regulating the densities of these is of little practical interest; it finds its application chiefly in aeronautics.

EFFECT OF HEAT ON GASES.

Heat has a powerful expansive effect on gases. From the freezing to the boiling point of water, air is expanded ·367 parts of its original volume, or 36·7 per cent. One hundred volumes of air at 32°, will occupy 136·7 volumes when heated to 212°. This makes, for each degree of heat, an expansion of ·00204.

PRESSURE OF AIR BY GRAVITY.

The atmospheric pressure is fifteen pounds to the square inch on a vacuum, or equal to the pressure of a column of water thirty-four feet high at the sea-shore, and under ordinary circumstances. If a vacuum, or partial vacuum, is produced, as in pumps, the water surrounding the lower orifice of the pump will be pressed, in an attempt to regain its equilibrium, into the pipe by the force of the atmospheric air; and if water and air are perfectly exhausted from the pipe, the water must rise thirty-four feet high. In practice it is almost impossible to effect these conditions; and two-thirds of the whole height of the perfect vacuum, or twenty-two feet only, can be depended upon as effected by good pumping machines.

CHAPTER VI.

LAWS OF MOTION IN FLUIDS AND GASES.

EFFLUX.

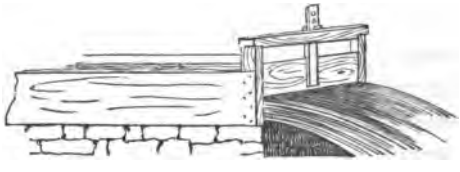
WATER contained in a close vessel will bear on all sides of the vessel with a force equal to its mass and pressure. If an aperture is in the vessel, the water will flow out with a velocity belonging to the height of the column of water above the orifice. This velocity is equal to the final velocity of a free falling body, measured from the surface of the water to the middle of the opening. The velocity of a free falling body at the end of its way is $\sqrt{2 \times g \times h}$; and in case no loss of speed is caused by the orifice, the speed of the water through the orifice must be $\sqrt{2 \times g \times h}$. In this formula, g is the velocity in feet of a free falling body in the first second, and h the height in feet of the surface of water above the centre of the orifice. In equal forms of apertures and equal sizes, the velocity of the water in the apertures is as the square roots of the heights.

This latter is a very important principle; it is not only correct in its application to water, but holds true with all liquids, fluids and gases. The velocity belonging to a column of quicksilver, of the same height as that of water, is the same in both cases. If the height of quicksilver is in proportion to the specific gravities of the two fluids, their velocities at the aperture will be inversely as the roots of their specific gravities. If air is confined and pressed out at an orifice, the velocity will be as the square

root of the height of the column of air, or as the pressure. In practice, the real velocities are in most cases smaller than the above formula indicates, as is shown in the contraction of the fluid vein. The form of the orifices has much influence upon the quantity of water discharged. For the sake of convenience, we assume in all cases a mean velocity. The velocity of a fluid vein is different in the different parts of a section, which circumstance would embarrass the operator; it is therefore avoided by substituting a mean velocity. The mean velocity of water issuing through a rectangular cut in the side of a vessel, or a wier, is two-thirds of the velocity at the sill, or the lower edge of the cut.

When the surface of the water is above the upper edge of the vein, and head water is pressing upon it, the aperture appears as a difference of two cuts, and the law, however modified, is the same. If the gate in fig. 53 is opened

Fig. 53.



$1\frac{1}{2}$ foot high, the width being 3 feet, and the sill $2\frac{3}{4}$ feet below the surface of the water; the discharge is then, $D = \frac{2}{3} \times 8{\cdot}02 \times 3 \times (2{\cdot}75\frac{3}{2} - 1{\cdot}25\frac{3}{2}) = 16{\cdot}04 \times (4{\cdot}125 - 1{\cdot}875) = 16{\cdot}04 \times 2{\cdot}25 = 36{\cdot}9$ cubic feet. In this formula is 8·02, the permanent coefficient of loss in velocity in this instance. If the side of the vessel, or the gate as in fig. 53, be not vertical, but inclined, we substitute

the vertical size; this is not quite correct, but it is very nearly so.

The efflux of water is in a great measure regulated by the form of the aperture, and by the thickness of its walls. When the smallest side of an aperture is larger than the wall, as is generally the case, the contraction of the vein is very strong, and in most cases the water does not touch the sides of the orifice. If the side of the vessel is thick, or if the walls of the aperture are thicker than its smallest side, as is particularly the case where short pipes are inserted, the vein is to all appearance parallel, and uniformly as thick as the aperture is wide.

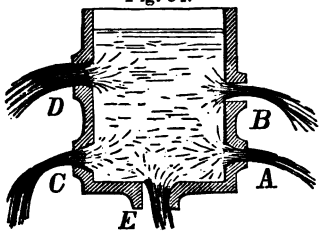
The velocity through a thin side — that is, an aperture where the side is not as thick as the smallest side of an aperture — is in all cases nearly equal to the formula $\sqrt{2 \times g \times h}$. In the appendix a table is annexed, showing the heights and velocities in this case. If the form of the aperture is that of a short pipe — that is, if the thickness of the side is one, or one and a half times the size of the aperture — the mean velocity for the middle of the aperture is to be multiplied by ·82. The values in the table referred to are to be multiplied by this number. The theoretical is very different from the practical velocity; the latter depends upon many circumstances which must be taken into consideration.

The quantity of water discharged is always in proportion to the contraction of the vein. This contraction is caused by the form of the aperture; it is also influenced by the size, the length of the discharge pipe, the head of water, and in many instances by the form of the channels which conduct the water from the point of discharge.

POSITION OF THE APERTURE.

If the aperture is not quite at the bottom of the vessel, or near its sides, and is one and a half or twice its smallest side from the bottom or sides, the contraction of the vein is perfect, and no disturbing influences interfere with it.

Fig. 54.



This is shown in fig. 54, at the opening A, where the curved form of the mouth-piece attracts every particle of the water in a gentle curve, causing no whirls, such as will happen at the aperture B. In the latter case, the cylindrical part of the mouth-piece is of no use; for the outside corners of the aperture act as if the discharge was in an extremely thin plate. Table V. of the appendix shows the coefficient by which the velocities in Table IV. are to be multiplied, to obtain the actual discharge of water in this case. This table shows that the quantity of water discharged diminishes with the increase of the height, or head, and is a little greater by small orifices than by larger openings.

The actual quantity of water discharged from an orifice is easily calculated by using Table V; this, however, applies only to orifices in extremely thin walls, or such as B, fig. 54; that is, in all cases where a perfect contraction of the liquid vein is accomplished. It applies also to those cases where the orifice is submerged under the discharged water. In the latter case, the head-water is the difference between the two surfaces of water.

THE QUANTITY OF WATER DISCHARGED

In one second, from an orifice of 8 inches square by 31 inches head, into the air, by perfect contraction, is equal $13 \times \cdot 6 \times \frac{1}{3} = 3 \cdot 46$ cubic feet. If the discharge is covered by back-water, the rule is the same taking the actual head. If the water is on one side 14 feet high, and on the other side only 10 feet, there is 4 feet fall; the velocity to 4 feet head is 15·9 feet, and the coefficient to 4 feet is by an orifice of 4 inches square ·61. An opening of 4 inches under that head will discharge ($\frac{16}{144} = \frac{1}{9}$ square foot is the orifice) $D = \frac{1}{9} \times \cdot 61 \times 15 \cdot 9 = 1 \cdot 7$ cubic foot per second. If the orifices are larger than those marked in the table, the coefficient of the largest opening may be applied with but slight inaccuracy.

If the orifice is long, or the walls so thick as to form of the aperture a kind of mouth-piece, then the vein is more or less perfectly parallel, filling the aperture and showing no contraction, as in A and D, fig. 54. The fluid vein is always formed by the orifice; and as there are a great variety of orifices, the veins of course assume an indefinite variety of forms. In these cases the actual discharge is, when three sides of the vein are contracted, 1·035 times the coefficient of Table V.; 1·072 times, when two sides are contracted; and 1·125 times, when one side is contracted. In applying this rule, the coefficient is multiplied by the number belonging to the contraction, and the theoretical quantity multiplied by it. If one side at an eight-inch square opening is contracted, such as E, fig. 54, and the head is 31 inches, the quantity discharged will be, $D = (1 \cdot 125 \times \cdot 6) \times 13 \times \frac{1}{3} = \cdot 675 \times 13 \times \frac{1}{3} = 3 \cdot 8$ cubic feet.

DISCHARGE THROUGH GATES.

Flood-gates and other gates have their orifices generally close at the bottom; when such is the case, the coefficient ·625 is adopted, which, however, gives the quantity of water discharged too small. If the orifices or gates are close together, the quantity discharged is very small, on account of the turbulent motion in the back water; in this case the coefficient is not more than ·55, or ·5. This diminished discharge is perceptible where the gates are from six to ten feet apart.

If both sides and the bottom of a wooden water-race are parallel to each other, and the gate is inclined, as is frequently the case at water-wheels, the coefficient, should the inclination be 45°, is ·80; and if the inclination is 67½°, the coefficient is ·74. Here it is understood that the height of the aperture is measured vertically.

Fig. 55.

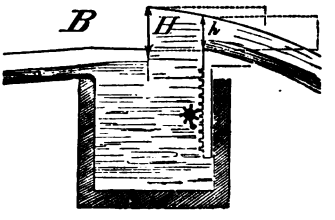
In fig. 55, A is the plumb-line which forms the vertical. If the inclination to that plumb-line is 45°, we multiply by ·80; and if the declination from that line is 22½°, we use the coefficient ·74. If the gates are provided with mouth-pieces, as in fig. 55, B, which is often the case at overshot and breast-wheels, the actual discharge is then found by multiplying the horizontal area of each opening, not covered by the gate, by the velocity belonging to the middle of each of the smallest sides; the product of all the orifices, multiplied by the coefficient ·75, is the actual discharge.

In the discharge of water in the prolongation of a water

race, or wooden trough, the coefficient is not much affected if the head at the gate is not less than one foot; with a smaller head of water, there is some loss in friction. The whole difference resulting from such diminutions of the actual discharge varies between ·55 and ·65, or, more correctly, ·55 and ·6; so that, for practical purposes, a slight modification only is allowed.

DISCHARGE OVER A WIER.

Fig. 56.



The volume of water discharged over a wier, fig. 56, is found by applying the coefficient ·405; this, however, alludes to the height H, where no perceptible lowering of the level occurs. If we here take H the fall or height of head-water, and apply the common formula $\sqrt{2 \times g \times H}$, or the velocity calculated in Table IV., multiplying this by the width and the height H, and the product by the coefficient ·405, we obtain the quantity of water which passes over the wier. If the width of the wier is equal to the width of the race or canal, the quantity of water discharged is a little larger, and the coefficient ·42 may be applied.

In those cases where it is not in our power to measure the actual height, that is, H from the level surface, we are compelled to measure the thickness of the vein on the comb or top of the wier. In these cases, H is equal to 1·178 h, when h is the height above the comb of the dam, fig. 56, and the latter smaller than the width of the race or canal. H is = 1·25 h, when the wier and canal are of the same width.

If a wier is provided with a short trough, fig. 56, B, in which the water is conducted, as on common overshot wheels, the formula is essentially different from the foregoing. In this case, the friction caused in the channel diminishes the amount of water considerably, and the coefficient decreases with the decrement of depth. To make this more clear, as it is a subject of frequent occurrence, we give below a table which shows the coefficient belonging to various depths. In this case, the theoretical quantity is $\sqrt{2 \times g \times h}$, times the width and depth, and the coefficients applied to that formula, or the velocity of Table IV. for the formula. In all these cases, the velocity is measured in the middle of the vein.

Height of water above the bottom of the trough in inches.						
	8	5½	4	2½	1½	1
Coefficient, ...	·319,	·314,	·305,	·283,	·272,	·227.

If the water is higher than eight inches, the coefficient for eight inches is used.

THE DETERMINATION OF A QUANTITY OF WATER

In a race, a canal, or a river, may be found by applying the coefficients to the formula, in case there are dams, wiers, or other means by which to measure it; but if this is not the case, we cannot apply the above rules. The quantity of water in a spring or a well, may be determined by dipping it, by means of buckets, and keeping it constantly level at the same height. If buckets are not sufficient, pumps may be applied; and the water thus withdrawn in a certain period of time, is measured by gallons, barrels, cubic feet, or any other measure or weight.

THE QUANTITY OF WATER PASSING IN A CANAL.

In a canal so constructed as to afford a regular velocity, and a uniform section, the quantity of water in it, and that which passes a certain point, may be determined by various means. The most convenient method is to measure the velocity, at the surface of the water, by a floating object, which dips so deep as not to be materially affected by the air or wind. We find then the mean velocity by applying the coefficients of the following table to the velocity on the surface.

Velocity in ft., per sec.	·328,	1·6,	3·28,	4·92,	6·56,	8·2,	9·84,	11·4,	13.
Coefficient.	·760,	·786,	·812,	·832,	·848,	·862,	·873,	·883,	·891.

To a velocity still less than the smallest in the table, the first column is applied.

The determination of the quantity is not difficult in this instance: it requires but a simple multiplication of all the factors, or the velocity at the surface, by the coefficient and the profile. In determining or measuring the velocity at the surface, some caution is necessary to prevent errors; the safest way to proceed is the following:—Make blocks of wood, (of which the best form is a square,) of white oak or beech, or such kind of wood as is nearly of the same specific gravity with water. Throw these blocks into the channel, or strongest current of the canal. A string is now suspended across the canal, so as to touch nearly its surface. The blocks are thrown in, above the string, and the time observed when they pass it: a watch which beats seconds, or a pendulum made of a leaden ball and a silken string, which vibrates once or twice in a second, suspended in a quiet place, is the measure of time. The blocks are watched, to observe how much time is consumed in passing a certain length of the canal—the longer that space, the

more reliance can be had upon the accuracy of the operation: the section of the length measured must be equally wide and uniformly deep. The length of the floated distance divided by the time (one second) is the velocity of the water on the surface. To be perfectly safe in measuring the velocity, the experiment must be repeated several times.

There are other methods proposed for measuring the velocity of water in channels, but they are not more perfect than that described, and still more complicated, for which reasons we do not allude to them.

THE VELOCITY OF WATER ON THE BOTTOM AND SIDES OF A CANAL

Is less than that in the middle. The velocity on the surface is greater than the mean; thus the lesser and the greater are equalized by the coefficient of the last table. The actual velocity on the bottom is W=QM—V, in which M is the mean velocity, and V the velocity at the surface.

ABRASION OF THE BOTTOM OF A CANAL

Depends on the velocity of the water which moves over it, provided the canal is not cut into solid rock, or built of stones, wood, or iron. The velocity of water, if greater than that noted in the following table, will carry away particles of corresponding matter.

Loam or clay is washed away by a velocity of				2·9	inch.
Tenacious clay	"	"	"	5·8	"
Sand	"	"	"	11·6	"
Gravel	"	"	"	23	"
Large rounded gravel		"	"	25	"
Stones	"	"	"	46	"
Slate	"	"	"	57	"
Slaty rock	"	"	"	70	"

VELOCITY IN CHANNELS

Which conduct the water from a gate to a water-wheel, is generally that of the velocity in the gate; still it is necessary, in practice, to take less than the formula for the gate developes, particularly where the velocity is great, or the channel small. The rules given in a former paragraph, for spouts, can be applied here, but not to that extent. If a channel or race is long, the effect of the sides and bottom of the trough on the velocity is considerable. Friction diminishes it throughout the whole length, and the velocity is, of course, the smallest at the end of the trough. It is frequently a desirable object to know the velocity at the end of such a channel: it may be obtained by dividing the quantity of water which passes, by the section of the fluid vein. The quantity of water may be obtained at the gate, in the usual way; and if there is no gate, from the wier.

THE LOSS OF FALL,

By conducting water through pipes below ground, is, in many cases considerable. Such arrangement is necessary where water is conducted from reservoirs through dams upon wheels, or used for other purposes. The loss in pressure or head-water is easily ascertained, in practice, by erecting a vertical small pipe upon the end of the discharge-pipe, before the water leaves that pipe. Cases of discharge through subterranean pipes are frequent; they are often resorted to, to lead water upon wheels, or supply other reservoirs. The subject is more intricate than it at first sight appears to be, but we will insert the formula for determining the loss in these cases. If H is the actual head above the centre of the discharge-pipe in the first re-

servoir; h, the head above the centre of the pipe in the second reservoir; M, the coefficient for the gate at the mouth of the pipe in the first reservoir; m, the coefficient for the gate at the second reservoir; A, the section of the pipe; a, the opening of the gate at the second reservoir; S, the circumference of the pipe; and L, the length of the pipe, the loss in head-water, or the difference between both heads, is $H - h = \frac{m^2 \times a^2}{A^2} \times \left[\left(\frac{1}{M} - 1\right) + 1 + \cdot 007 \times \frac{S}{A} L\right] \times h$.

From these investigations it follows, that such subterranean conductors of water cause a great loss of power; and it is, for these reasons, advisable to avoid such second pools. In case it cannot be avoided, the pipe ought to be as short and wide as possible.

FORM OF CURVE OF THE LIQUID VEIN.

In connection with overshot water-wheels, it is frequently a question to be decided, in forming the buckets of the wheel, what kind of a curve, and what curve in a particular case, the liquid vein forms. The centre of the vein always describes a parabola, the form of which depends on the angle by which it starts from the gate, or from the trough; that angle depends on the velocity in the gate, or over the wier. With these elements, in all practical cases, a parabola is easily constructed.

SIZE OF CANALS AND WATER-RACES.

Head and tail races for water-wheels ought to be as regular and uniform as possible, to avoid whirls and counter currents, which cause a loss of power. If the side-walls of these canals are of stone or wood, they are generally vertical; in such cases it is most advantageous to make the depth of water about half as great as the race is

wide. If the bottom and sides of the canal are rough, the width should be four or six times as much as the depth of water. If the localities are of such a nature as that no choice of section can be made, attention is required that the velocity of the water be not too great, so as to expose the canal or race to destruction, by its washing away the sides and bottom. By referring to a former table, the practical velocity may be found. If we multiply the quantity of water which is to pass in the channel by the profile, we obtain the velocity of water. If we assume this to be the mean velocity, we find the velocity at the bottom by referring to the table on page 173, which alludes to this subject. If the fall of a canal or race is given, we are to find the velocity belonging to this fall; and according to that velocity, the canal is to be provided with material to resist the injurious action of the water.

WATER CONDUCTED IN PIPES.

In all cases, water-pipes should be cylindrical, and free from obstructions and narrow passages; angles and bends should also be avoided, and, if actually necessary, the bend should be of the longest possible radius. The amount of water conducted through straight pipes, which flows freely into the atmosphere, is represented in the formula $V = 26{\cdot}44 \sqrt{\frac{D \times H}{L + 54 \times D}}$, in which V is the velocity, D the diameter of the pipe, H the head of water over the centre of the pipe, and L the length of the pipe. If the discharge of water is obstructed, or leads the mouth of the pipe into back water, the difference between the head on one side and the head on the other is = H. If the velocity is thus found, the quantity of water which passes through the pipe is $q = \frac{D^2 \times V}{1{\cdot}273}$.

SIZE OF PIPES.

When it is desired to lay a pipe which is to conduct a certain quantity of water to the best advantage, it is advisable to bring as many known elements into the formula as possible. In these cases, the length, the quantity to be conducted, and the height of the fall, are generally known; and there are only the diameter and the velocity to be determined, which is not a difficult operation if we apply the above formula. If it is impossible to avoid angles in pipes which are to conduct water, it is advisable to make the pipes from one-third to one-fourth wider than they would be if straight.

DISCHARGE OF WATER FROM RESERVOIRS.

At locks in canals, it sometimes happens that water is discharged from a reservoir without supply; the question here is, to ascertain how long a time it will take to withdraw the water from a lock by the valves or discharge gates. If water flows from a basin which has no supply, the surface of the water will gradually sink, and at last it will be on a level with the back-water. The velocities of water from an aperture are as the square roots of the pressure, or head-water; this law, the same as that of free descent, can be expressed by a triangle. The space passed over by a free descending body in a certain time is similar to the surface of a triangle whose basis is t, or the time of descent, and whose height is v, or the velocity. The triangle is $\frac{vt}{2}$, and so is the space of free descent. A body which moves from the beginning of descent uniformly with the same velocity, will pass twice that space; that is, vt. The latter illustration may be applied to a discharge of

water where the head is constantly the same, as the flood-gate at a lock. The first illustration with the triangle is applicable in those cases where no supply of water is furnished, and the head-water, or surface, gradually sinks to the level of the discharge. To find the quantity of water discharged from a reservoir without supply, is therefore simple; it is equal to the amount discharged by supply, divided by two. We have been speaking of the discharge by constant supply, and there is no need of analyzing this case. It follows from this, that the time in which a basin may be discharged by a sinking surface, is twice as long as if the head-water was permanent. If a reservoir is divided by a partition, and there is in this partition an aperture which discharges the water from one side to the other; the time required for such a discharge may be calculated on the above principles. This subject, however, is not of much importance, and is of but rare application.

DISCHARGE OF WATER FROM LARGE BASINS.

If a basin is to be emptied in a certain time, it is first necessary to inquire whether the lower grounds will be flooded or injured by the discharge, and what time it will take to empty the basin. If all the measures of the pond or lake are known, a profile and length of the discharge channel are obtained, and the latter also levelled. If all these measures are given, we obtain the quantity of water, and then calculate whether the banks of the discharge channel are safe, whether the fall is sufficient to prevent overflow, and how long it will take to discharge the pool. All these points may be ascertained by applying previous paragraphs.

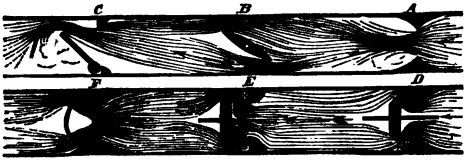
The practical rules are, here, to make the discharge trough of equal width with the channel, and put the bottom

of it on a level with the bottom of the channel. The height of head is then divided into certain equal quantities or parts, according to the time of discharge, and the discharge gate drawn so high as to discharge, in the stipulated time, one quantity of water. The opening of the gate is found by dividing the quantity of water to be discharged in one second, by the velocity belonging to the fall, Tables IV. and V. By taking this down to the bottom of the gate, the quantity discharged will be a little smaller than calculated. The area of the opening, multiplied by its coefficient, is to be equal to the above divisions. By these means, the time of discharge, size of channel, and probable danger of floods, may be calculated beforehand.

FORM OF VALVES.

The reflections on the contraction of the fluid vein are of great practical importance, particularly if we apply them to the valves and passages in water-pipes. In fig. 57, the

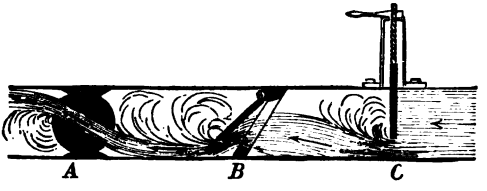
Fig. 57.



inside collar, A, will cause quite a contraction; a throttle valve, B, causes a double contraction; the trap valve, C, causes one only, but a serious decrease of the fluid vein. Such contractions as at D, where conical valves are used, cause a great deal of loss in velocity; the valve E is not

much better. F is the best form of a valve, if its position is vertical. In horizontal pipes, the common slide valve A, fig. 58, and if possible square, is the best form. The

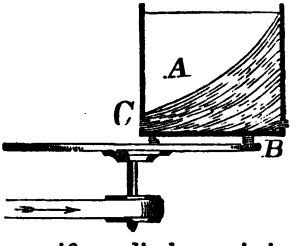
Fig. 58.



trap B, and the cogs C, are very imperfect means of regulating the passage of fluids. The best valves are those which cause the least contraction of the fluid vein.

DISCHARGING VESSELS IN MOTION.

Fig. 59.



If a vessel, A, fig. 59, is set in motion, and revolves around an axis, the surface of the water will form a parabola. The orifice B, which is the farthest from the centre of rotation, will discharge more water than the orifice C, which is nearer to the axis. The ratio in which these orifices discharge is in proportion to the head on each orifice, provided the apertures are at rest, or are constructed in such a manner as not to interfere with the rotary motion of the liquid. It is not difficult, therefore, to calculate the efflux of water from such vessels, if we know the velocity of the rotary motion. The head at the orifice B is known by centrifugal force; and as that force is known, we find the height over

B by applying it. It is here evident that we can increase the velocity at B so far, that C retains no water at all; and if the efflux is as great as the supply, C may always be dry. This law is not altered if the discharging vessel is covered. We shall refer to this subject again, in speaking of reaction water-wheels.

BACKING OF A RIVER BY A DAM.

When a dam or wier is laid across a river, the height of the water above the comb of the dam may be found by previous formulæ. If the surface of water from the dam, backward, was a perfect level, it would not be difficult to determine its swell along the banks of the river. But this is not the case; the water retains velocity, consequently, fall. If we imagine or draw a level or horizontal line, from the highest point of the water-level near the dam, this line will cut the bed of the river somewhere, and the backing of the water will go as far as if the water was at rest. Various experiments and calculations led to the conclusion that the slacking surface was $1\frac{1}{2}$ times as long as the level surface, which, in many practical cases, may be true. This law, however, is by no means general; the length of the slack-water line depends chiefly on the velocity of the current, therefore on the size of the channel, and the quantity of water discharged. The length of the line is then, of course, related to the square of the velocity. The formula for this subject is $= \frac{H}{P} - 1{\cdot}3 \times V^2$, wherein H is the length of slack water from the dam to the bed of the river, measured at the respective surfaces of the water. P is the fall of the river belonging to the length; H and V is the velocity of the head-water, above the dam. In most practi-

cal cases, $1\frac{1}{2}$ times the length of the level will be nearly correct; which number should be increased, if the velocity is small, and diminished when rapid.

BACKING A RIVER BY CONTRACTION.

The same laws which are applied to investigate the backing caused by a dam, are made use of in this case. A contraction may be considered an imperfect dam. The water passes it with increased velocity, in case the quantity of water is increased, and the velocity corresponds with the height of the water passing. If, in this instance, we know the level of the river above the point of contraction, we may apply the rules of the last paragraph.

BACKING BY PIERS.

The sum of the passages between the piers of a bridge, subtracted from the width of the river above it, is the amount of contraction. The same rule can be applied here as in the above case, if the level above the piers can be actually measured; but if we calculate the velocity between the piers, and deduct from that velocity the height to which the river will rise above them, we are to multiply the result by ·855, if the piers are rounded, and by ·95, if they are sharpened at the face, because of their friction, and the disturbances in the current. On account of the increased velocity caused by a contraction of a river, the river-bed below it will be deepened, in consequence of which the height above the contraction is always less than that found by calculation.

WATER AS MOTIVE POWER.

Water in motion may act by impulse or concussion, by its weight, and by reaction. If a stable or slowly-moving

body is met by a rapid current of water, the same laws which are applied in similar cases to solid matter, are applicable here. The moving body imparts to the one at rest all the velocity with which it arrives, and in consequence it is at rest. The action of water is different in appearance from that of solid matter, because here is an indefinite number of small bodies, following one another in rapid succession: it assumes the action of a spring, constantly pressing with a certain amount of force, but never with its whole power. The laws governing this case, however, are similar to those applied to solid matter, given in former pages. The impulse of one and the same mass of water, under similar circumstances, is proportional to the velocity of the water; and for an equal transverse section of the stream, the impulse against a surface at rest increases therefore as the square of its velocity. The impulse of water against a plane surface is an equivalent of the weight of a column of water whose base is equal to the transverse section of the stream, and twice the height belonging to its velocity. If the aperture is closed, and the water at rest, the pressure upon it is simply as its height; but the water being in motion, the pressure upon the closing valve is twice the height. The force against the receiving-plane is considerably increased, if the plane is not much larger than the aperture, and is surrounded by an elevated rib. When the direction of the fluid vein is not perpendicular, but is oblique, upon the receiving-plane, the effect is diminished, and is in proportion to the sinus of the angle in which the direction of the vein touches the plane. The following table shows this relation:

Angle of the vein to the plane.	90°, 70·16°, 50·16°, 39·46°, 30·16°, 26·16°.
Proportion of effect.	1, ·90, ·72, ·40, ·29, ·18.

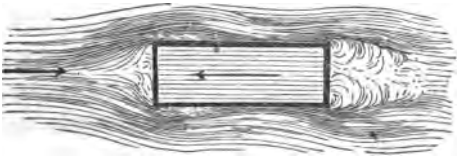
IN THE MOVABLE PLANE

The effect of the impulse is diminished, in case the plane recedes, and increased, if the plane moves against the current: the proportions in this case are either — or +, according to the direction of the plane. The velocity of the motion, in case the plane recedes, is V—U; when V, the velocity of water, U that of the plane; and it is V+U when the plane moves against the current. These velocities are, of course, in relation to the form of the plane, such as the buckets of a water-wheel.

UNLIMITED STREAM.

If the impulse of water is acting against a floating vessel, it offers not only a resistance against its face, but it presses also on all sides of it; the velocity of its motion will therefore depend upon its form. If the water and vessel have the same velocity, the form of the latter, of course, is indifferent; but if the velocities are different, the case is not the same. In a prism with square ends, the water being at rest, and the first floating, the pressure on each point of its surface is equal to the same level; but if the water is in motion, and it moves in the direction of the

Fig. 60.



axis of the prism, the veins of water will be diverted from their parallel course before they touch the prism, as is represented in fig. 60. The mass of water is in consequence

reduced into a smaller space, and by the sudden conversion from its course, it is set in turbulent motion, which increases its resistance. At the fore part of the prism, or the keel, a portion of water is sent in an opposite direction to the general motion, and increases the resistance of the vessel by its counteraction. A portion of water is carried away, by the force of the current, from the stern, and a consequent lowering of the water-level ensues, which inclines the vessel to sink into this depression of level. In this case it is not only the loss in friction which diminishes the resisting force of the vessel, but the difference of level at the bow and stern. The pressure of the water is less at the stern, and more at the bow, than the average pressure of the fluid, and the resistance of the vessel to the motion of the water increases accordingly. If the prism is perfectly straight on both sides, the pressure is equal; but if the sides are uneven, the pressure is unequal, and the vessel will be moved to the side where the resistance is least. The resistance of a plane surface to the impulse of water increases with its surface: that is, if a small surface offers a certain resistance to the current, expressed in per-centage of the impulse force, the larger surface will afford a greater per centage than the smaller. The laws by which this subject is regulated are not developed, however important they are in respect to propellers of steamboats.

When the paddle of a water-wheel, either of a side-wheel on a steamboat, or an undershot wheel, is exposed to the impulse of water, the water will rise before the paddle, forming a higher surface than the general level; this rise is higher in the middle of the paddle than at either end. The water in this case follows the laws of gravity, and moves from the middle towards the ends. It is evident

from this that long paddles of the same surface must be of greater effect than short paddles. We arrive at the same conclusion if we examine the water behind the paddles; in consequence of the motion of either wheel or water, the level will be lower behind the paddle than the general level, and will be lowest in the middle of the paddle, because the water flows from both ends to fill the depression: the wider the paddle, therefore, the more time will be required to fill that depression. The difference of level between the water before and behind the paddle, is the measure of resistance. From these and the foregoing investigations, it follows that if the paddles are inclined, and not parallel to the axis of the wheel, the resistance is smaller because the action is in an oblique direction, which loss is shown in the last table. If the paddles are curved in a certain direction, some resistance may be gained; but of this we shall speak hereafter.

IMPEDIMENTS TO MOTION.

The resistance of water to the impediments to its motion is equal, or in proportion to, the squares of the velocities. If the paddle of a side-wheel on a steamboat moves with twice its former velocity, the water will resist it four times. If a current of water, moving in a channel, is led upon a plane surface, such as the paddles of an undershot wheel, the effect is nearly equal to that of a vein of the same size, working upon an indefinite plane, or upon a plane enclosed by elevated borders. The law of resistance, as above defined, is applicable only to thin plane surfaces; if the surface is curved, the law is more or less modified; and if the surface acted upon has any thickness, the resistance is increased. If the length or thickness of a resisting plane is equal to one of the sides of the plane, or, more generally

speaking, equal to the square root of that plane, the resistance of the sides to the motion of water is nearly one-fifth of the surface, and diminishes with the length. When the direction of the current is oblique to the plane, its force is considerably diminished; the bow of a ship is constructed on this principle. The resistance varies according to the angle of the plane or bow, and is nearly in ratio to the squares of the sinuses, which law, however, extends only to the angle of 180°, and thence to 120°. Angles of less degree have no connection with that rule, as the following table shows:

Angle of the bow,	180°	156°	132°	108°	84°	60°	36°	12°
Ratio of resistance,	1	·95	·85	·69	·54	·44	·41	·40

The angle at the stern of a vessel has a similar effect upon the resistance of the floating body, as is shown in the subjoined table:

Angle at the stern,	180°	96°	48°	24°
Ratio of resistance,	1	·89	·86	·84

This shows that the angle at the stern is not of so much influence in diminishing the resistance as the angle at the bow.

In the foregoing calculations, the angle is simply applied to plane surfaces; if these surfaces are curved, as in ships, the resistance is greatly diminished. Experiments show that when the resistance of a plane surface is 100, that of half an ellipsis is 52, and that of a triangle with broken or angular sides 43. Theoretical investigations have not succeeded in determining the form of least resistance, and practice has not yet furnished any rules for it. This is a subject of grave importance to navigators, and ought to be solved by the constructors of vessels. In general terms, it is

agreed that a well-constructed ship will offer one-fifth of the resistance of a prism of equal length and section with the ship. In the best instances, this resistance has been reduced to ·15 and ·16. The form of least resistance appears to be that of a fish, of which the fleetest swimmers may be considered the best patterns.

RESISTANCE IN A CANAL.

When a floating vessel moves in a canal of limited dimensions, the resistance is increased to that in unlimited water. The water before the bow is driven higher than the mean level, and its surface forms an inclined plane from bow to stern. The smaller the canal, the greater will be the angle of that inclined plane; for in that case the friction on the bottom and sides of the canal diminishes the velocity, which is the only means to restore the mean level. The vessel is in these instances inclined to sink into the trough, or lowest part of the surface of the water; and a certain power is required to lift the vessel out of that position. These resistances are shown in the following observations, wherein the vessel, in all instances, is of the same form, and moved with the same velocities:

Space on each side of the vessel in feet.	Space below the bottom in feet.	Ratio of resistance.
unlimited	unlimited	1·00
"	·135	1·10
"	·029	1.15
2·03	·031	1.52
·70	·027	2·26
·02	·027	3·15

The resistance increases here more rapidly than the amount of water diminishes between the vessel and the sides of the

canal. This relation is dependent on the size or cross section of the vessel and that of the canal. In the above experiments, a displacement of water of nearly 2·26 feet section, by 6 feet long, was produced. It is therefore bad policy to make narrow canals. In these instances, the resistance increases as the squares of the velocities, taking all the impediments to motion into consideration. If the section of a canal is 6·46 larger than the section of the floating body, the resistance is equal to that in unlimited water, provided the width of the canal is four times that of the width of the vessel at the water line.

WATER AS MOTIVE POWER.

Water in motion may be considered as a moving machine, preceding another machine, and imparting motion to it. We are therefore to investigate what force the water possesses, and what force it imparts to the receiver of that force. The description of machines which derive force from water have either a rotary or an oscillatory motion. An active force or power is a combination of force and motion, and is expressed by multiplying the one by the other. In all cases, we apply as a measure of active force a certain weight lifted to a certain height, which is expressed, by general agreement, by one pound lifted 33,000 feet high in one minute, or 33,000 pounds lifted one foot high in one minute. This is called a horse-power, because we assume that a horse can perform so much labour in that time. The active force of water is therefore simply expressed by multiplying the height, or head of water, by the weight which is in motion, or discharged in one minute. If a machine which receives the water in motion were so perfect as to transmit all the force received, the calculation of the effect would be obtained by simply multiplying the

height of fall by the weight of water discharged in one minute. This result is, however, modified by the form of the receiving machine; and the diminishing influence is expressed by a coefficient adapted to the various kinds of machines.

LOSSES OF EFFECT.

The diminishing influences on the effect of water in a water-wheel are various. A part of the power is lost in an undershot wheel by passing at the ends, and below the paddles, without effect on the wheel. A portion is lost in all wheels by the distance between the wheel and gate; a portion by friction in the gate and buckets, and by the turbulent motion in the buckets; and another portion is lost in friction between the journals and pans of the axis of the wheel. There are many other causes of loss, which we shall mention hereafter.

After subtracting all these various losses from the first element of power, that is, the height of fall and weight of water discharged, we obtain the actual result of labour performed. The number of machines for transmitting the inherent power of water is great, and each has its advantages and disadvantages, according to locality and execution. The labour performed by these machines is not always in accordance with the results of calculation, which may be assignable to the peculiar execution in each case.

THE RATIO OF LABOUR PERFORMED

To the power received, forms a constant coefficient in every instance. This labour is, however, never equal to the power received; it is always less. But the labour performed is always equal to the resistance, which affords a means to measure that labour. Experimental investigations have shown that a machine which transmits the power

of water never performs more labour than $\frac{3}{4}$ or 75 per cent. of that received; in many cases it is less than 50 per cent., and in some instances less than 25 per cent.

WATER-WHEELS.

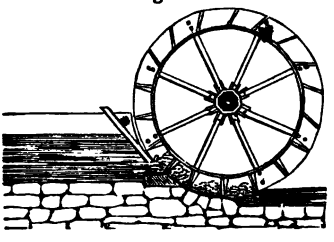
The water-wheels in use are of various forms, and constructed on a variety of principles. There are wheels with radial buckets or paddle-wheels, moving in channels, or in unlimited water, about a horizontal or a vertical axis; wheels which receive the water more or less above or below their axis, or breast-wheels; wheels which receive the water at or near the highest point of their circumference, or overshot wheels; and wheels in which the vertical direction of the current is converted into a centrifugal current; and reaction wheels.

UNDERSHOT-WHEELS.

These kind of wheels are chiefly employed where the head of water is low, or where a great velocity is to be imparted to a small wheel, so as to perform many revolutions in a certain time—such as paddle-wheels at saw-mills. The paddles of these wheels generally move in channels; in other cases, as in open rivers, and on steamboats, they move in unlimited water. In the construction of all wheels, particular attention must be paid to the form of the gate leading from the forebay to the wheel; for if the vein of water contracts a great deal after its issue, a proportional amount of power is lost, which, in excessive cases, may amount to three-fourths of the whole power. How to construct a gate of least contraction, may be found in former pages. The gate ought to be as near as possible to the wheel, and the contraction of the vein ought to fall upon the centre of the paddle. In inclining the gate towards

the tangent of the wheel, the gate may be brought nearer to the periphery, as is shown in fig. 61. The chief loss in these wheels is that caused by the contraction of the vein, for which reason particular attention must be paid to it. The size of the paddles is so regulated that the amount of water, when flowing in the open channel, is never deeper than ten inches, and not less than six: in calculating the depth the diminished velocity of the water in the channel is taken into consideration. It is of importance to have the spaces between the buckets and the channel as narrow as possible, without touching the bottom or sides. The radial depth of the paddle is to be sufficiently high to receive all the water from the gate without losing any over the top of the paddle: in most instances the width of the paddle is sufficient, if it is three times the depth of the vein in the channel. The distance from one paddle to the other, at the periphery of the wheel, is to be equal to the width of a paddle. The diameter of a wheel is arbitrary, and subject to practice; no rules can be assigned for its limits. The speed of the buckets, measured at the circumference of the wheels, is, however, related to the amount of labour performed by it; and this decides, in most instances, the diameter of the wheel. In some cases it has been proposed to make heavy wheels, and let them act as fly-wheels. This is a bad speculation, for the water is a permanently equal force—it needs no regulator: and if a fly-wheel is needed, as is the case in iron works, it is more profitable to employ a separate fly-wheel, which has a greater velocity

Fig. 61.



than a water-wheel can possibly attain. In some instances the paddles of wheels have been made inclined toward the radius, as represented on a part of the wheel in fig. 61; but this is of no use in wheels which run in channels, for the simple reason that the paddles form an inclined plane to the vein. Wheels which work in unlimited water may be provided with inclined paddles, in some instances; but the advantages are so insignificant that this subject is of little importance. Paddles provided with projecting borders are also of little use, as the water adheres too much to them.

SPEED OF A WHEEL.

The speed of an undershot wheel, in performing the greatest amount of labour, is equal to half the velocity of the water in the channel. The velocity of the water is found by ascertaining the velocity in the gate, and multiplying it by the coefficients of contraction and friction. This applies to the centres of the paddles, or the circle running through these centres.

THE LABOUR PERFORMED

By an undershot wheel, cannot be more than one-half of the active force of water, if nothing is lost by the wheel and gate, because the paddles of the wheel recede with half the velocity of the moving force, and this force is therefore divided. As the loss of velocity in the vein, from the gate to where it touches the wheel, and from friction, is equal to one-half of the theoretical velocity, the labour performed by the wheel cannot be more than 25 per cent., or one-fourth of the power, in the forebay. Experiments made on differently constructed wheels, by various persons, agree in the main, that the labour performed to

the power applied, is less in proportion as the speed of the wheel increases. The velocity of the wheel ought never to exceed half that of the water, measured in the centre of the vein: the velocity at the sides and surface being less than the latter, it will be necessary to make the required corrections, in case the velocity is found by actual measurement. If a difference in speed is made by undershot wheels, to the ratio of velocities, it is advisable to run the wheel slower than half the swiftness of the water; and in all practical cases the greatest effect is obtained by making the velocity of the wheel ·45 of that of the mean velocity of the water. Well-constructed undershot wheels, with radial paddles, if larger than 20 feet in diameter, may perform 33 per cent., or one-third of the power imparted; if less than 20 feet in diameter, the labour performed is reduced, and will, in small wheels, not amount to more than 25 per cent. Ill-constructed wheels will not afford as much as 20 per cent. of the active force; and they are found to effect, in many cases, not more than 10 per cent. of that force. This happens in small paddle-wheels, which frequently are found to work under a considerable head, driving saw-mills.

WHEELS IN UNLIMITED WATER,

Such as move in the current of a river, where the natural current propels the wheel, are not often found of a large diameter, seldom exceeding 12 or 15 feet; a greater diameter, however, does no harm, and is often found necessary, particularly where the wheel is employed for hoisting water. The size and direction of the paddles is in this case of some consequence; their width is generally one-fourth of the radius of the wheel; some millwrights take one-fifth of the radius. The length of the paddles is

determined by the labour they are to perform. In case the channel or river in which the wheel is to work, has its greatest velocity below the surface, the paddles of the wheel ought to dip deep enough to reach that velocity. Where the greatest velocity is at the surface of the water, or near it, it is of little consequence how deep the paddles dip, provided they afford sufficient working-surface to perform the labour expected. The water acts upon these wheels by impulse; but if we incline the paddles to the diameter, so that the water rises upon them, and works in the mean time by its weight, we may increase the effect of a wheel considerably. It has been ascertained by experiment, that an inclination of the paddle of 30° to the radius of the wheel is most profitable, generally speaking; but this inclination varies according to the velocity of the current—it is greater in a rapid, and less in a slow current. The effect is still increased if the paddles are curved, so as to offer a concave surface to the entering water. The most labour is performed by these wheels when the velocity of the paddles is a little less than half that of the current. If the surface of the paddles which are submerged be multiplied by the velocity of the current, and the product by ·40, the difference of velocity, and that again by ·50, the loss of labour in the wheel, we shall very nearly obtain its effect, which is about 20 per cent. of the active force of the water.

WHEELS OF A STEAMBOAT.

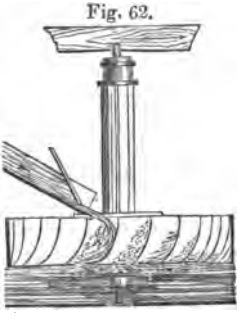
The labour performed by paddle-wheels on steamboats is calculated in the same manner as the above wheels; but here the speed of the boat has an influence upon the result. If a steamboat is at rest, the effect of the wheels will be similar to the effect of stationary wheels in unlimited water;

they will move the boat with a force equal to about twenty or twenty-five per cent. of the power applied. The effect of the steam-engine upon the paddles is equal to the force applied by the engine upon the paddles, because no power can be lost but that by friction from the engine to the wheel, and the actual labour of the wheel upon the water must be equal to the pressure of the paddles, multiplied by their velocity. If the boat is immovable, the effect of the paddles will be that imparted by the engine, less the velocity of the current behind the wheel; that is, the faster the wheel moves, the smaller will be its effect. From this it follows, that the boat in moving against the current will lose accordingly, and, in moving with the current, gain, because the speed of the paddles must be increased in the first case, and can be diminished in the latter. The resistance of a steamboat hull varies from twenty to forty-five per cent. to the resistance of a prism of equal section, according to the form of the vessel. The labour performed by the wheels increases with the surface of the paddles, and it is therefore advantageous to make them as large as practice will admit of.

HORIZONTAL WHEELS.

In many instances we find undershot wheels with a vertical axis; these are employed in grist-mills and factories, chiefly with a view to simplify machinery. These wheels generally perform little labour, but, if well constructed, they may be as effective as vertical wheels. The water is led upon these wheels by means of an open trough, as shown

Fig. 62.



in fig. 62, or by a gate affixed to a forebay. If the paddles are inclined to the axis, as shown, the effect is considerably increased; and if the discharge of the paddles is narrow, so as to retain the water, and convert a part of its velocity into centrifugal force, as in reaction wheels, the labour performed may be largely augmented.

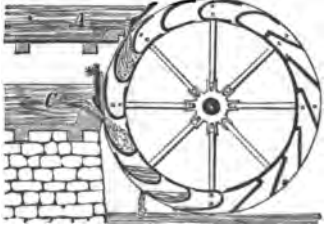
BUCKET WHEELS.

Radial paddles do not perform the greatest amount of labour in transferring power; curved paddles, or buckets, are in most cases more effective; this is particularly the case where the water, either in whole or in part, is used to work by its own weight — where the head-water is variable, and where back-water influences the effect of the wheel.

OVERSHOT WHEELS.

If the fall or head of water is more than twelve feet, it is advisable to use the weight of water, and introduce it upon the wheel, either in its highest point, or a little below that point. The diameter of a wheel is in this instance most advantageous if it is equal to the whole fall, and the water is conducted upon the wheel below its highest point, as shown in fig. 63, A. If this is inadmissible, as may happen in practical cases, the water is introduced above the top of the wheel; and if circumstances render it necessary to make the wheel considerably larger than the whole fall, the water is led upon it, as shown in C. In all instances, the form of the bucket is of considerable influence on the labour

Fig. 63.



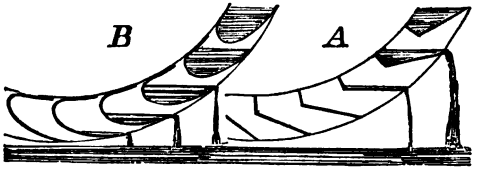
performed by the wheel, but not so much in the entrance of the water, as in its discharge. The manner of leading the water into the buckets is so calculated, that the velocity of the vein in issuing from the gate of the forebay is a little greater than the velocity of the circumference of the wheel; and that the greatest contraction of the vein falls in the opening between the buckets at the periphery.

The contraction of the vein is, for reasons given before, to be as slight as possible; to accomplish which, the opening of the gate is wider inside than outside, and the sides so curved as to be trumpet-shaped. The gate is also formed in such a manner as to direct the vein of water into the buckets, so as to make it fall upon the bottom of the buckets. The gate is to be only three-fourths of the width of the wheel, and as close as possible to it. The vein of water must not be allowed to touch the back of the buckets. The width of the wheel is dependent upon the amount of water it is designed to consume; and it is a good rule to make the wheel so wide that each bucket will contain only one-third of the quantity of water for which it has capacity. This rule requires that the breadth of the wheel-ring, or depth of the bucket, should be decided upon before the width of the wheel is determined. The depth of the buckets is arbitrary; but in practice it has been found that more than fifteen, or less than six inches, is not advantageous. This depth should not be more than twelve inches, to which an ultimate opening of two inches of the gate ought to be applied. These dimensions will form a capacity of wooden buckets for three times the amount of water, and of iron buckets for four times the quantity. The speed of the circumference of the wheel is in practice found to be the most profitable, if it is a little less than half the height of the free descent of bodies in the

first second; that is, less than eight feet. More labour will be performed by the wheel if it moves at a slower rate than that; but this renders it necessary to increase the size of the wheel, and all the machinery connected with it, so that little is gained by a less speed. The loss of power in a bucket-wheel is partly above the entrance of the water, and partly below the point where the buckets commence discharging. The loss above the entrance is chiefly that where the vein enters the bucket, because here the water cannot impart motion; there is no object upon which it can act. As this loss depends upon the distance from the gate, it is advisable to have the gate as near as possible, and the depth of the buckets as small as possible. Another loss is in the contraction of the vein; but this has been alluded to before. In the best case, half of the height of head-water above the opening in the gate is lost; and as this height can never be less than eighteen inches, nine inches of the whole fall are lost in all instances. This loss, in a majority of cases, amounts to the whole head in the fore-bay above the aperture of the gate.

The loss of power below the point of discharge depends on the form of the buckets, as well as the height of that discharge above the back-water. The sooner the water is

Fig. 64.



discharged from the buckets, the greater the loss. Wooden buckets are more subject to this loss than those of iron, as represented in fig. 64, where A shows the position of the

wooden, and B that of curved iron buckets. This loss is considerably less in large than in small wheels, and increases with the velocity of the wheel. It is therefore an advantage to make large wheels, if circumstances permit. The velocity of the wheel has an influence upon the discharge of the water, by increasing its centrifugal force, which force will drive the water towards the circumference of the wheel, and elevate the level of the water in the buckets towards the periphery, causing a more rapid and also a premature discharge. The loss caused by the centrifugal force is particularly great at small wheels, and those which run with great speed, as wheels for driving tilt-hammers in iron forges. The labour performed by such wheels is therefore very small, and their erection can only be justified by expediency. The effect of such small wheels may be considerably augmented by putting a box around that part of the wheel where the water operates, which converts it into an undershot wheel.

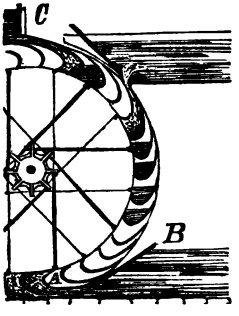
From the foregoing considerations, it follows that an overshot or a bucket-wheel will perform the most labour, when its gate is perfect. The slower the motion of the wheel, the smaller the difference between the velocity of the water and the rim of the wheel, and the more correct the curve which forms the outside of the bucket. A large wheel will perform more labour than a small one, at the same head, and a light wheel more than a heavy one. In practice all these laws are more or less modified by localities, and we are compelled, in most cases, to subject our theoretical speculations to a particular case.

CURVED BUCKETS

Have a decided advantage over straight or angular buckets, and wheels ought to be constructed on that prin-

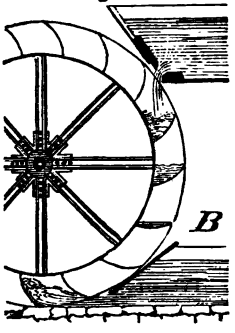
ciple in all cases where it is practicable. Theoretical investigations may determine the form of the curve of a bucket, in all instances, but they would lead us farther than our space admits of. We represent therefore, in two drawings, the principle involved, in a practical form. In fig. 65 the curve of a bucket adapted to an overshot wheel is represented. The wheel, when just as high as the head-water, will afford a forebay of water two feet deep, which, in passing through the gate, gives a velocity of vein of about thirteen feet; this is twice as much, or nearly so, as the speed of the wheel. In this case the mouth of the bucket may be narrow, merely wide enough to receive all the water, provided the bottom of the wheel is so far open as to admit the escape of air from the bucket. In this as in all other instances, the direction of the centre of the vein must fall together with the prolonged line of the bucket curve, or else some of the force of the water will be expended in holding back the next bucket: this is particularly difficult to accomplish with wooden buckets. The curve of the bucket, in fig. 65, is adapted to an overshot, but not to an undershot wheel, as shown in the same, fig. B. The bucket, A, not lying in the direction of the fluid vein, is held back by the pressure of the vein, and a great loss of power is the consequence; the water in entering the bucket is also set in turbulent motion, and reacts upon the following bucket. The strong curvature of the bucket prevents the discharge of water in time, and a portion of it will be lifted too far above the tail-water, which of course absorbs power. A

Fig. 65.



strongly-curved bucket is therefore not qualified to work to advantage in an undershot wheel.

Fig. 66.



In fig. 66 a bucket is represented which is better adapted to an undershot wheel. The part B shows at a glance that this bucket receives the water more properly than that in the last figure. This form of bucket would also be more correct for an overshot wheel than the other, particularly in receiving the water; but it will discharge it very soon, and by taking the centrifugal force into consideration, we find that the form of this bucket will not afford the greatest effect. Strongly-curved buckets are advantageous in slow-moving overshot wheels. In cases where water is scarce, and where we want to perform the largest amount of labour by a given quantity of water, the strongly-curved bucket, and a moderate speed of the wheel, is the best arrangement. The wheel must be calculated to receive the water with ease, retain it as long as possible, and discharge it with facility. In an undershot wheel the curve of the bucket must be more limited, where the head of water is low. Where the bucket touches the bottom of the wheel, the curve starts in the direction of the radius, and the edge of the bucket where it receives the water must be of such a form as to dip into the current, instead of exposing its curved side to the vein, as in the case of the strongly-curved bucket shown in A, fig. 65. The water in an undershot, and any other wheel, is to leave it at its lowest point, and should not be carried up behind the wheel, which will happen by strongly-curved buckets and great speed of the wheel. The retaining of

water in the buckets of a wheel, is caused partly by the form of the bucket, and partly by the speed of the wheel. In the latter case the tangental direction of the current is transformed into a radial direction by the centrifugal force, consequently the water is lifted behind the wheel to a height corresponding to the speed of the wheel and curve of the bucket.

In summing up all the circumstances which have a bearing upon the form of the buckets, we find that the slower the wheel moves, and the higher it receives the water, the more curved the bucket may be. If a wheel receives the water on the top, as in C, fig. 65, the curve of the bucket may fall together with the tangent of the wheel. An undershot wheel, which receives little or no fall, must have radial, or very gently curved buckets. Between these two extremes are the forms of the curve, according to the height at which the wheel receives the water. A breast-wheel cannot, therefore, have a strongly-curved bucket, nor a radial paddle, to perform the largest amount of labour with a certain quantity of water. The speed of the wheel is another element bearing upon the form of the bucket. A very slow-moving undershot wheel may have a strongly-curved bucket, but a wheel moving with great velocity should have a radial bucket, to make it discharge its water at the lowest point.

The material of which a wheel is built has a decided influence upon the labour it will perform. Theoretically the buckets ought to have no body at all: nearest to this is thin sheet iron, with sharp edges to receive the water. The bucket ought to be perfectly water-tight; still there must be sufficient room in the bottom of the wheel for the escape of the air from the bucket: for these reasons wheels which receive the water at the highest point are unprofit-

able, because they will leak. A sheet-iron bucket bent, and formed of one sheet, as represented in fig. 65, is, for these reasons, the most perfect in practice. The weight of a wheel is to be as small as possible, on account of the friction caused by a heavy mass. Wooden wheels, in this respect, have an advantage over cast-iron ones; but those made entirely of sheet-iron, where the buckets are riveted to the sides, and the arms are of wrought iron, as represented in fig. 65, are the most perfect.

THE LABOUR PERFORMED

By these wheels, from a certain quantity of water, depends therefore entirely on their form; that is, the size of the wheel, the shape of the buckets and gate, and their weight. It ranges from ten per cent., in a very imperfect undershot or small overshot wheel, used in saw-mills and forges, to 65 per cent. of the active force of water in slow-moving, light wheels, with curved buckets. It does not make any difference in these results, if the wheel has more or less fall or head of water, if it works on the principle of an undershot or overshot wheel; it depends entirely on the conditions of its form. We have not alluded to breast-wheels with open buckets or paddles, because they are unsuitable, and deficient in an important point, namely, the water-tight bucket. In cases where great speed of the wheel is necessary, as in saw-mills, or iron forges for driving tilt-hammers, the best effect is produced by employing small undershot wheels with curved buckets, having the velocity of the whole head of water upon them.

HORIZONTAL OR REACTION WHEELS,

Are wheels moving about a vertical shaft. The name "reaction wheel" is incorrect, and does not indicate the

true meaning; these wheels are, properly speaking, centrifugal wheels. The direction of the motion of water in them is either partly converted from the direction of gravity into a radial motion from the axis of the wheel, or into a centrifugal motion, or centrifugal force. These wheels have considerable advantages over vertical wheels, partly because of the position of the shaft, which qualifies them peculiarly for grist-mills; partly because they occupy but a small space, and use little material; but chiefly on account of their velocity, which simplifies all other machinery connected with them. We shall therefore pay more attention to this form of wheel than we have done to other varieties.

It was demonstrated, a century ago, by eminent engineers, that this was the most perfect form for a water-wheel; and all subsequent experience has shown the correctness of the conclusion. Still, these wheels have not yet arrived at the perfection which they must have in order to find general application as a first mover in factories. The difficulty appears to be chiefly in the variable form of the wheel, in its adaptation to particular cases. Learned engineers have demonstrated its principles, and laid down formulæ for general use; but, notwithstanding this, failures are very frequent. We shall not attempt a learned investigation of this subject, but confine ourselves to the development of the principles involved, in common language, accessible to all.

If we take a common vertical undershot wheel, and lay it horizontally — that is, put its axis vertical — and lead the vein of water in a broad sheet into the buckets, or upon the paddles of the wheel, it would require an indefinitely narrow wheel to obtain the greatest effect, because the head in this case is spent uselessly in the width of the wheel.

If we extend the paddles of the common wheel more to the centre, and introduce the water near that centre, the fall belonging to the width, or in this case the height, of the wheel, is lost, because the discharge is above the level of the tail-water. Where the head-water is low, a great deal of power is thus wasted in the height of the wheel. If we submerge the wheel to its upper rim, the water which is introduced at or near the centre flows out at the periphery, and, in acting upon the back-water, reacts apparently upon the wheel, which caused this wheel to be called "reaction wheel." This term was originally derived from Barker's water-wheel, which received the water in a revolving cylinder, and discharged it at its lower extremity, either directly from the circumference of the cylinder, in a tangental direction, or from a short pipe inserted in the periphery. This latter wheel, in forcing a current of water against the atmospheric air, or against a solid object, may be considered as a reaction wheel; but it has no relation to the kind of wheels at present in use. There is a possibility of constructing a wheel which may act as a true reaction wheel; but there are not many cases in practice where they would be applicable. Wheels which have to discharge a large quantity of water cannot be propelled to advantage on these principles. In neglecting all those imperfect machines which belong to this class of wheels, we shall endeavour to show the principles involved in those constructions which have been the most successful.

FOURNEYRON'S WHEEL.

The first practical wheel of this kind was constructed in France. Its principles contain all the elements of a good wheel; still, there are limits in the execution of those principles, which render its success very difficult. The wheel

is represented in fig. 67, in a vertical section; and in fig. 68, in a horizontal section, taken through the middle of the wheel. The water, in entering above the wheel from A, sinks down upon the bottom B, which is fastened to and

Fig. 67.

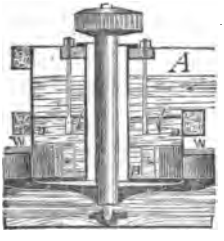
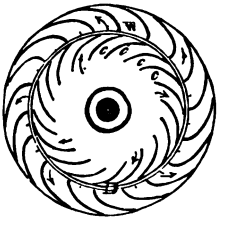


Fig. 68.



suspended from a hollow stationary shaft, or pipe. This bottom carries the curves *c c c*, which are guides, and conduct the water from the interior of the machine to the wheel. These guides convert the vertical motion of the water into a horizontal motion, and direct its current inclined to the tangent of the bottom. These curves, which are made of sheet-iron, are so many apertures for conducting the water, and their size is regulated by a circular gate of sheet-iron, D, which may be moved vertically up and down.

The chief objections to this wheel are, a loss of power in the motion of the water from the forebay into the space A, its motion here downward, and the sudden conversion of that vertical motion into a horizontal motion; which latter loss is increased by the curved form of the guides. This forces the natural current of water into a peculiar form, which can never be done with impunity.

The loss of velocity in water by forcing it through curved pipes is great, and ought to be avoided by all

means. The disadvantages arising from this circumstance are experienced to their full extent in the machine under notice. From these orifices the water is conducted into the wheel W, and strikes the curved buckets in a direction which ought to be the radial direction, if we consider the motion of the wheel. The principles which are at the foundation in constructing the guide-curves and the curves of the wheel-buckets, are, that the water is to enter the latter without producing any direct action upon the wheel, or causing a turbulent motion of the water in the wheel or gates. This principle is easily laid down, but not so easily executed; for there are almost insurmountable difficulties in determining the curves, and, where mathematicians fail, it is of no use for a merely practical man to try. The form of these curves is not the same in each particular case; it differs in every instance where the quantity of water, and the diameter and speed of the wheel, are different. After the water enters the wheel, it is whirled round with it, and part of its velocity, derived from gravity, is converted into horizontal motion and centrifugal force. If the wheel is correctly constructed, the velocity of the water when arriving at the periphery of the wheel is = 0, or the centrifugal force and gravitation are equal; the water will drop from the wheel without motion.

To determine the form of the curves for buckets and guides is a difficult mathematical problem, and is beyond the limits of this work. When a liquid vein touches an inclined plane, as has been demonstrated in previous pages, that plane will move at right angles with the centre of the vein. The inclined plane will move with a uniform velocity, corresponding in some instances with the sinus of the angle of inclination. If the free action of the current of the vein is interrupted, this law is considerably altered, and

is of an intricate nature; this invariably happens with turbines, and causes the difficulty in constructing the curves. The curve of the bucket is to be a line on which the water, in passing from the centre in a radial direction, touches under an angle of 45°.

We arrive in a practical way at the solution of this question, if we construct a curve with the velocity of the wheel, to which the interior and exterior diameter of the rim furnish the elements; that is, a line which a loose point will describe, while the wheel moves round with its calculated velocity, in running from the interior to the exterior circumference. This line forms one side to a parallelogram of forces, the other side of which is found by describing that line which the centre of the vein of water will form in moving from the interior of the rim of the wheel to the exterior. The diagonal drawn to these two lines, which of course are both curves, is the correct line for the curvature of the bucket.

If this form is correctly executed, the water will arrive at the exterior periphery with exhausted velocity, provided the rim is sufficiently broad, the curve long enough, and the openings of discharge not too large. The above elements for the construction of the curve are not the same in all instances; they change with the speed of the wheel and the velocity of the water, for which reasons a correct curve of the bucket can only exist under similar conditions; that is, a certain speed of the wheel, an equal head of water, and a regular supply. These conditions apply to wheels performing a regular amount of labour: if more or less than the amount calculated is required, the curve is incorrect. For these reasons we do not consider this a practicable wheel, because the conditions under which it furnishes the largest amount of labour from a given ele

ment of power, cannot be complied with, in practice, or at the best but in few instances, such as factories, which consume a uniform quantity of water, and do not vary the labour of the wheel. These water-wheels, for various other reasons, are not practical machines, which, together with the difficulty in constructing a good one, has been the cause of their not being more in use.

If these wheels are properly constructed, and the conditions of their use complied with, that is, equality of speed, and a regular supply of water, they are superior to those of any other form in their yield of power. Wheels of this kind may supply 75, and even as high as 80 per cent. of the active force of water, which is a result not attainable by those of any other form. But at the same time, wheels have been put up which yielded only 20 per cent., or less, of the power applied, and were, of course, total failures. There is however a practical way to build good wheels of this kind, and we will relate our own experience in the matter. In constructing a wheel of this description, we were led to consider the guide-curves as so many gates, and constructed them accordingly, making them as short as possible, so as tc form a correct vein, of small contraction, for propelling the wheel, and conducting it into the buckets, so as to form a direct action upon them. The curves for the buckets in the wheel were constructed on the true principles laid down above; but in the execution, care was taken to remove the buckets when they were found insufficient. The theory, in that instance, gave rather a large opening for discharge, which inclined me to doubt the efficiency of the wheel. On trial, it did not furnish 20 per cent. of the force applied, and of course it was condemned. The buckets with the two rims, which were made of sheet-iron, were now removed, and another wheel screwed in, the

gates, shaft, bottom, and the size, of course, being the same. In this instance the curvature of the wheel was increased so as to form a stronger curve than the diagonal to the speed of the wheel and the velocity of the water, the discharge at the circumference being made considerably larger than they would be if the designed quantity of water was to flow through them, in case these openings served as gates for the discharge of a vessel at rest. This second wheel afforded about 40 per cent. of the power applied, which still could not be considered sufficient to guarantee success. The second wheel was now removed, and a third screwed in. In this the curves formed an ellipsis, falling together with the radius on the interior diameter, and with the tangent, or nearly so, on the large diameter. The discharge was now reduced to 1·25 of that size required to discharge the water from a vessel at rest. This wheel afforded 75 per cent., exclusive of friction, and as that was five per cent. of the water applied, its actual yield was 80 per cent.

The foregoing shows that the practical difficulties are not insurmountable, provided the wheel is designed to perform a certain amount of labour constantly, such as for blast machines at furnaces, or in a cotton or woollen factory. In all instances, however, where a variable power is required, and the amount of water limited, so as to make a saving of water desirable, and to afford a constant yield in all cases, these wheels are useless. In constructing a wheel of this kind there is no necessity for referring to complicated mathematical laws; those elementary principles laid down in previous pages of this book are all-sufficient.

In forming the plan of a centrifugal wheel of this description, it is advisable to bring the sill of the forebay as low down upon the wheel as possible, to avoid an unneces-

sary velocity of water before it enters the curved gates. The diameter of the wheel should be sufficiently large to afford room for the descent of water in the centre of the machine; the velocity of the descent should not be more than one foot per second. The sheet-iron guide-curves, which may be cast into the cast-iron bottom, are to be very smooth; all scales and roughness should be removed by filing. These curves must be as short as possible, merely calculated to give to the vein the form of least contraction: the same principle is here applied as in any other gate. The direction of the vein is not very material, but it is proper to let its centre be 45° to the tangent of the circumference of the gate. The rim of the wheel should move as close as possible to the guide-curves, affording, of course, room for the cylindrical gate of sheet-iron, which moves between the wheel and the guides. The width of the wheel, or the difference in its inside and outside radius, should not be less than ten inches; it is of no use making it more than one foot. The height of the wheel, that is, the distance between one rim and the other, depends on the quantity of water discharged, and is inversely as the velocity of the water. In the smallest wheels the height is not less than two inches, and in the largest not more than twelve. The number of buckets is not essential to its effect; too many cause too much friction, and too few too large an opening at the discharge. The distance of the buckets in the small circle of the wheel is not less than two inches, and seldom more than four. The number of guide-curves may be equal to those of the buckets, but in large wheels there are frequently found three buckets to one guide. In all cases we should take an odd number of guides, if the number of buckets is even; or the case may be reversed. This will avoid those vibrations of the

wheel which may happen in consequence of the regularities of the veins issuing from the gates. In all instances the relative sizes of the gate, and of the discharge apertures at the circumference of the wheel, must be so arranged that the first will supply more water than the latter can discharge, and the wheel be always filled with water. If this condition is complied with, other matters are not very essential; but if this is not the case, the best construction of all the parts of the wheel will not prevent its failure. The speed of the wheel is, in successful cases, equal to the velocity of the water; that is, the velocity of the circumference, on the largest diameter, is nearly equal to that with which the water would flow from an aperture, under that head or fall, if its discharge was through an opening at the bottom into the atmospheric air.

REACTION WHEEL.

We shall not dwell upon this subject to an undue extent, because these wheels afford too little power to deserve more than a passing notice; there is, however, a feature developed in some of them which deserves attention, as a condition of success in centrifugal wheels. A reaction wheel with two or more arms, which may be either curved or straight, is represented in fig. 69, in a vertical section, and in fig. 70, in a horizontal section. The water enters here from below, and the surface of the hollow shaft is so large as to afford an upward pressure equal to the gravity of the whole machine. The water is conducted through the hollow arms, and escapes at the apertures in the ends of these arms with a velocity belonging to the head of water, minus friction in the pipes. The water, in passing out at the apertures, strikes against a circular wall made of stones, which is close to the apertures, and causes the arms to

recede. If the whole machine formed one cylinder of a diameter nearly equal to the diameter of the cylindrical wall around it, and the water issued at the bottom and

Fig. 69.

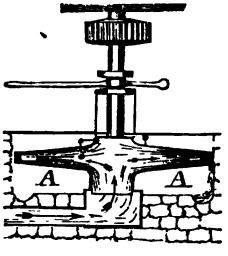
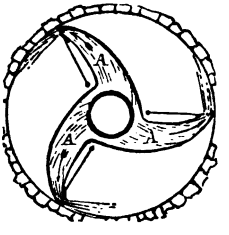


Fig. 70.



periphery of that cylinder, we should have a true reaction wheel; but the arms of this wheel alter that condition. If no centrifugal action of the water upon the curve of the arms happened, the case would be the same as in a cylinder. A form of arms may be arrived at upon which no action of the water would affect motion; but that would lead to a disadvantage. If the wheel is propelled as a purely reaction wheel, the same laws apply here as those applied in the undershot wheel, but to a greater disadvantage. If the arms of this wheel are curved on the principle of a centrifugal wheel, all the advantages of that wheel may be obtained, minus friction in the long and rough pipes. The feature which advantageously distinguishes this wheel is, that the gate to regulate the efflux is at its point of action; this removes the difficulty in the filling of the wheel, which is the chief cause of loss in all centrifugal wheels. The apertures are here closed, and more or less opened by movable sliding valves, which are connected by means of rods with the axis of the wheel, and may be

moved either by a lever, by hand, or by a governor. This principle applied to the centrifugal wheel removes all objections to these otherwise useful machines.

IMPROVED CENTRIFUGAL WHEELS.

Recently a description of horizontal water-wheels have been constructed in this country, which deserve more than common attention, partly on account of their simplicity, and partly on account of the principle involved. A vertical section is represented in fig. 71, and in fig. 72 a plan

Fig. 71.

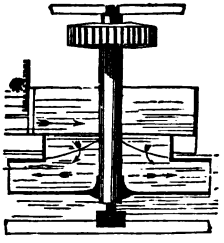
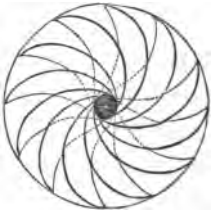


Fig. 72.



of the wheel. This is simply a vertical shaft, to which the wheel is affixed; the forebay conducts the water directly into the wheel without any guide-curves, the quantity of water being regulated by a flood-gate in the forebay. The water here works partially vertically upon the buckets, and is discharged at the circumference of the wheel. At the periphery, the direction of the buckets is vertical upon the rims of the wheel, and at the interior they are inclined about 45°, so that the bucket forms a twisted curve. The motion of the water in the centre, before it enters the wheel, is vertical, and, in descending upon the oblique bucket, has a tendency to move that vessel, which here ex-

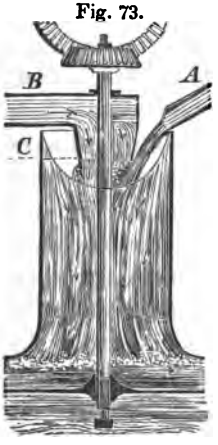
poses an inclined plane to the direction of the water. The motion of the water is from this point gradually converted into horizontal or radial motion, and the wheel assumes the character of a centrifugal wheel.

Improvements to this wheel have been proposed, namely, to conduct the water from the forebay around the shaft in a spiral form, so as to arrive in the wheel with a centrifugal force; but we cannot perceive any advantage to the above wheel in this addition; the circular motion of water from the bay before it enters the wheel is only so much loss, caused by friction against the enclosure. This wheel, in its simple form, is perfect, provided the discharge of water can be regulated at the periphery of the wheel, instead of in the forebay, and this regulation so adjusted that the wheel may be submerged in water, without causing a turbulent motion in the back-water.

The form of bucket is, in this case, a somewhat difficult matter to decide; still, we can arrive at sufficient elements by analyzing the wheel. When a particle of water, in its vertical descent, arrives at the wheel, it will have a tendency to move the bucket, if the bucket offers an inclined plane; this inclined plane has, however, a circular motion, and imparts that motion to the particle of water which follows it. If the velocity of the particle downward were equal to the horizontal speed of the wheel, an angle of 45° would leave the particle at rest upon the bucket. To produce motion by the descent of the water, the downward velocity of the water upon the wheel must be greater than the velocity of the wheel in that particular place where the water touches it first. If the speed of the wheel were the same in all its parts, there would be no difficulty in arriving at a satisfactory construction, and with little labour. At the centre of the wheel its velocity is very small, and any

velocity of the water is sufficient to produce action. At the extremity of the forebay, the velocity of the wheel is comparatively great, and the velocity of the supply is the same as in the centre. It is therefore advantageous to have the round opening in the forebay as small as possible, so as to feed the wheel chiefly from the centre. This opening must be so calculated as to furnish a velocity of water equal to the greatest speed of those parts of the wheel exposed to it, or the water will not enter the wheel. If the water could be made to assume a rotary motion before entering the wheel, the pressure on the buckets would be equal or in proportion to the velocity of the wheel, because the centrifugal force will cause the water to rise higher at the periphery than at the centre, as has been shown in previous pages. This condition cannot be realized where the water is conducted in a channel on the top of the wheel; it will answer perfectly, however, by introducing the water from below, and from the centre of the wheel. In this case, a cylinder revolving about its axis, as represented in fig. 73, will be a perfect form of a wheel, provided the buckets extend from the periphery to a considerable height into the cylinder. There will be a considerable loss in fall, however, because, in bringing the water into the centre, we have to elevate the channel, as shown in A; but if we close the forebay, as shown in B, we may conduct the water into the centre with a certain velocity, according to the speed of the wheel. It does not make any difference if the revolving cylinder is open at the top, or is

Fig. 73.

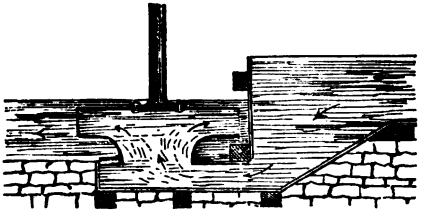


bent in or closed at the top; the pressure will be the same, for the centrifugal force will have the same effect upon the water, if in a closed or an open vessel; and we may make the cylinder as low as the line C without loss in power. If we make the cylinder higher than C, there is a loss caused by the friction of water in the central feeder B; and if the cylinder is lower than C, a loss by leakage ensues, and also a loss in power, because the velocity in B would be too large for the wheel. The proper velocity of water in the central feeder from B is that velocity with which the water sinks in the centre, and a little greater, so as to afford a sufficient supply to the wheel. The wheel represented in fig. 73 is not intended as a pattern for practical execution; it is merely designed to explain the principles involved in this question; for we shall find the wheel to be imperfect. The condition of feeding the wheel from B in the manner represented, would come near the truth, in case the head-water in the forebay and the absorption of the wheel were always the same; two conditions which cannot be realized in practice. This wheel is therefore as imperfect as any other known form of horizontal wheels.

If we reverse the wheel, and feed it from below, the case is quite different; all the imperfections are obviated, and we may arrive at a perfect form. This idea is represented in fig. 74. The water, in entering from below, will always form a connected vein, and its velocity will always correspond to the head or fall; no matter if the back-water raises upon the wheel, it will not affect that velocity, if the head-water rises also. The weight of the wheel may be made to correspond to the pressure upon it by the water at its entrance, which pressure is equal to that surface multiplied by the head of water, less the velocity with which the water enters and leaves the wheel.

The subterranean channel for conducting the water must be very large, or the loss in velocity is great, and forms a considerable coefficient, diminishing the effect of the wheel.

Fig. 74.



In this case we obtain all the inherent force of the water, provided the buckets are of an appropriate construction; they should be twisted curves, as described and represented in fig. 74. The form of this curve is not very material, if other important conditions are complied with; it is sufficient if the water, in entering, finds an inclined plane to act upon, and this inclined plane is continued on to its exit, considering the direction of the entering water as a vertical motion, and its exit in a horizontal direction. This inverted wheel has its disadvantages in practice; but the same principle may be applied in a right wheel.

Centrifugal wheels are to be submerged below the surface of the tail-water; it forms thus one of the greatest advantages of the horizontal wheel, and includes their superiority to the vertical wheel, working in back-water to greater advantage than the latter. To accomplish this, nothing else is required than to make the case of the wheel perfectly round and smooth, and construct the buckets in such a manner that the centre of each vein of water, in

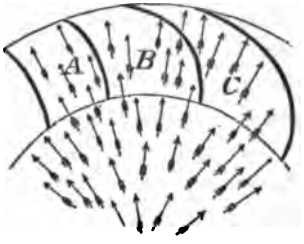
issuing from the wheel, falls in the tangent of its circumference. Wheels which do not form a round and perfectly smooth object are disadvantageous under water, and those which consist of arms only, ought not to be submerged at all. The immersion of the wheel affords another advantage, besides its making the best use of the fall at disposal, namely, its action as a reaction wheel, in case so much water is withdrawn from the wheel as that all the buckets cannot be filled; the retiring water, in issuing from the wheel, contains in this case an unexpended velocity, which acts on the surrounding water, and reacts upon the wheel.

FORM OF GATE.

There is no possibility of obtaining a good construction of a reaction or centrifugal wheel, until the gates for regulating the power of the wheel are at the very extremity of the issue, where all the power of the water has been exhausted before it is relieved. The gates are to be at the periphery of the wheel, and the issues must be regulated by these gates. We have shown, in fig. 69, the principle involved. All the passages for the water from the forebay to the wheel must be open and spacious, in order to lose as little velocity as possible, and to offer as little friction and obstruction to the water as room and means admit of. When the water enters the wheel, the case is different, as it has to impart its motion to solid matter; it is therefore to come in contact with solid matter, and remain so long in contact with it as to impart all its motion to the resistance. It is not sufficient that a body of water glides over solid matter; every particle of it ought to be in contact. Water is not very compressible; still, the friction between solid matter and water is by far superior to that between the particles of water; and the force of the particles in

the centre of the vein will escape unexpended, if they glide away with a greater velocity than the exterior particles. In fig. 75 is an illustration of the principle involved in this

Fig. 75.



case. The particles of water, arriving in a radial direction in the various buckets A, B, C, will escape very readily from A, without spending much work upon the resisting bucket; in B the case is not much better, and C will receive more than either A or B, because it affords the largest surface to the arriving particles. The only consideration which prevents an indefinite number of buckets from being most advantageous, is the friction of water on their surfaces; there is no other cause of limit. From the illustration it also appears, that the issue is to be the narrowest passage for the water; if all its force has not been exhausted upon the bucket before it leaves the wheel, it will act upon the surrounding water, and react upon the wheel. If, therefore, particles should escape which have not expended all their velocity inside of the wheel, they have to do so after leaving it, and impart to the wheel an appropriate amount of motion. There may be difficulties in constructing a perfect form of gates to centrifugal wheels; but we are convinced of a successful solution of this practical question; if our engineers and millwrights were only convinced of the correctness of the principles involved, their sagacity would soon lead to the discovery of a means

of perfecting that most useful of all water-wheels — the centrifugal wheel.

In the foregoing considerations of the horizontal wheel, we have purposely avoided alluding to particular constructions now in use, chiefly because none of them are perfect. We have endeavoured to present the principles of this subject in such general language as to make it accessible to practical men, without referring to mathematics.

WATER-PRESSURE ENGINES.

These machines are chiefly employed in lifting water from the bottom of a mine. They are constructed on the mechanical principles of a steam-engine, or a double-acting pump. The water is introduced into an iron cylinder, and forcing the piston in one direction, it moves another piston in a pump, and in this way lifts water from the bottom. The power of these machines is considerable, and amounts, in many cases, to ·75 of the force employed; but they are costly, complicated, and liable to get out of order. No machines of this kind are used in the United States, and we are doubtful if they ever will be; for these reasons we pay no attention to the subject. The principles employed in constructing water-pressure engines are the same as those used in erecting pumps.

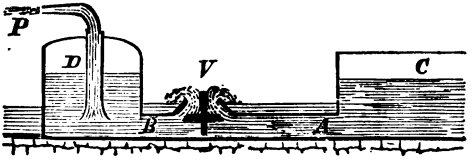
CHAIN-WHEELS.

Bucket-chains, rotary pumps as motors, and a variety of similar apparatus, are of little effect; they perform but little labour in comparison to the force applied; and as such machines are complicated, liable to accidents, and in no instance superior to well-constructed water-wheels, either vertical or horizontal, we abstain from entering on these subjects.

HYDRAULIC RAM.

This is a very simple and efficient machine for transmitting power, or raising water to a higher level. In fig. 76 a

Fig. 76.



hydraulic ram is represented. A, B, is a strong iron pipe, into which a current of water is conducted from a basin, C. This water, if in motion, will at first flow into the air-chamber, D, and when the pressure in that chamber is equal to the pressure in the pipe, the water will be at rest. The metal valve, V, will now open by its own gravity, and the water pass through the aperture; when the current of water is so strong as to lift the valve, it will shut again, and prevent the exit of water by these means. The impulse which the water received in passing out will open the valve at the air-chamber, and press some water into it, which will continue until the pressure in the pipe is not strong enough to hold the valve, V, to its seat, when it will open again. This play of the valves may be continued so long as the water in the pond, C, lasts, and while the pipe, P, is open. The mechanical power of these machines is considerable, and reaches, in well-executed cases, 65 per cent. of the force applied. This effect is measured by the difference between the height to which the water is driven at the pipe, P, and the head from the pond, C, multiplied by the respective quantities discharged. The best effects ever

obtained were 90 per cent., with a small machine. From this it follows that such machines are superior to most others for raising water, and in those cases where the quantity of water conducted is not too large, they are advantageous. The interior surface of the pipes must be very smooth, so as to cause as little friction as possible. The objections to the hydraulic ram are its shaking motions, the concussions of the valves in the pipes very soon destroying the one or the other; no foundation can be made strong enough to resist this force, in large machines. For these reasons, it is very doubtful if these otherwise remarkable contrivances will ever be employed to conduct strong power.

THE EFFECTS OF FIRST MOTORS,

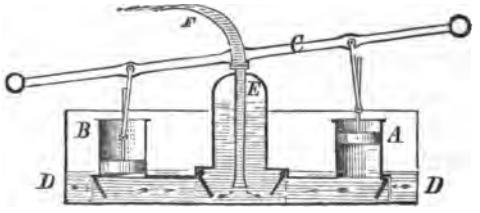
Or the labour performed by a machine transferring water-power, is variable; it depends on the principles of its construction, as well as their execution. If we assume that all the following enumerated machines are equally well executed, the labour performed by them will be, to the power applied, as the numbers appended: a good centrifugal wheel, 90 per cent.; a good overshot wheel, 75; an undershot wheel, 65; breast-wheels, 65; water-pressure machines, 80; common overshot wheels, water above the wheel, 55; common undershot, with radial paddles, 20 to 25; horizontal wheels, with radial paddles, 10 to 20 per cent.

PUMPS

Are well-known machines, either for raising or forcing water to higher levels. A pump is represented in fig. 77. We selected a double, single working pump, such as is generally used in fire-engines, because these are specimens of

well-constructed machines. It consists chiefly of two cylinders, A and B, in which pistons are moved, propelled by the beam or double lever, C. In lifting one of the pistons, water or air will be sucked in from D; if D is submerged, water only will pass into the cylinder, through the valve, from D.

Fig. 77.



In reversing the motion of the piston the first valve will shut, by the pressure of the inclosed water upon it, and the next valve will open, which passes the water into the air-chamber, E. The air contained in this, and partly forced into it by the water, is here compressed, and by its elasticity causes a uniform efflux from the pipe, F, by pressing upon the surface of the water. This machine, consequently, forms a regular stream of a certain velocity, notwithstanding its oscillating motion. The principle laid down in this pump, is the same in all other cases; the different innumerable forms of pumps are mere practical modifications of the same principle. The most important part of a pump is the cylinder and piston; if both do not fit closely, a large amount of power applied is lost by leakage. Wooden cylinders and pistons, packed with leather, are superior to metal, where muddy or sandy water is to be raised. In all cases where pure water is to be lifted, metal pumps, particularly cast-iron, are the best. The latter metal is suitable for pumps which are frequently

used; but where they are often out of use, as is the case with fire-engines, it is advisable to construct cylinders and pistons of brass, or still better, of bronze. Valves are constructed in a variety of forms, among which the trap-valve may be considered the best, if properly applied. Top-valves are useful, in many cases; but as a rule, the trap-valve is preferable to it for the passage of water. Pipes for conducting water to and from a pump, are subject to the same rules as any other water-conducting pipes; of the latter we have spoken before.

SUCTION-PUMP.

If we extend the pipe, D, in the last figure, downwards, and submerge the end of it below the surface of water, and lift the piston in the cylinder, the water will follow the piston, pass through the sleeping valve, and fill the cylinder, provided the piston closes tightly at its sides. The height to which water may be raised in the suction-pump, from the piston down to the water-level in a well, is equivalent to the pressure of the atmosphere upon a vacuum, which is the correct height of the quicksilver in the barometer, and of course the height in the pump varies with the variations in the height of the barometer. If the barometer is 30 inches, and the specific gravity of mercury 13·5, the height to which water ought to rise is $\frac{30 \times 13{\cdot}5}{12} = 33{\cdot}7$ feet. To this height water never rises, partly because it contains a little air, and some of it is converted into steam; besides which, the imperfections of the machine have an influence. In practice the height is calculated to be 20 feet. In very good pumps pure water may be raised to a height of 25 feet, impure water to less than 20 feet; and often it does not reach higher than six or eight feet, mea-

sured from the water-level to the piston. In constructing pumps it is of importance to make the dead space between the piston and the sleeping-valve as small as possible, on account of the air or vapours which may be formed. Gases are elastic, and any gas in this space will expand and diminish the power of the pump; this influence is particularly felt in pumps which work at intervals, and in those which throw hot water.

FORCE-PUMPS.

If we extend the cylinder of the pump vertically upward, and put a valve in the piston, we may raise the water as high above the piston as we choose, or at least as far as the pipes and piston-rod will bear its pressure. The pressure upon the piston and cylinder is equal to the vertical height of the column of water resting upon it, in case the piston is at rest; but the case is altered when the piston is in motion, as the resistance increases then with the squares of the velocities, and the friction in the pipes and valves. The column of water presses thus with a basis equal to the bore of the cylinder or surface of the piston, and the strength of a piston-rod may be easily calculated. In small pumps and low heights, the material is generally sufficiently strong if it resists the forces applied in working it; and no calculations are necessary to determine the strength of material; but if water is to be raised to a considerable height, and the quantity is not small, the strength of the parts of a pump are subjects to be determined by previous investigation.

In addition to the simple or theoretical pressure of water, we have also to consider the friction of the piston on the cylinder; the friction of the water on the sides of pipes and cylinder; the contraction and disturbances in the

valves; the weight of the valves, and the moment of inertia of the water: all these coefficients, which have a bearing upon the effect of a pump, are subject to practical arrangement and execution, and for these reasons are out of the reach of theoretical investigations; we may approximate a formula, but it can never be correct and applicable in all cases. In pumps which do not raise the water more than 40 feet above the piston, the resistance of the piston to the weight of water upon it may be as 10 to 9; by increasing the height or the quantity of water, this difference increases, and by diminishing the volume or height, the difference is less. A good pump may afford a yield from the applied power of 86 per cent. In practice we find, however, particularly in small pumps, not more than 50 per cent., and even less. The slower a pump piston moves, the more advantageous will be the consumption of the power applied. This law is limited in practice; but in common cases the speed of the piston ought not to be more than three feet per second.

A characteristic in pumps which deserves more attention than it generally receives, is the change in the motion of the piston. The manner in which these alternate oscillations are performed is of decided influence upon the effect of a pump. After a current of water has received an impulse, it is necessary that the motion imparted should be continued with an uniform velocity throughout its whole course; any change in that velocity will cause considerable loss in power by overcoming the inertia. The motion of a crank, moving in a circle with uniform speed, is therefore an imperfect machine for moving the piston of a pump, because the parallel motion which it imparts changes in every point of its course. The changes of a piston are to be sudden, and its velocity uniform. If any irregularities

in the motion of a pump-rod are advantageous, it is the reverse with the motion caused by a crank. If we insert between the power which moves the piston and the piston-rod, a spring, and compress this spring so as to impart a sudden impulse to the piston while returning from the extremity of its motion, we find a considerable gain in the effect of the machine; the amount of water thrown by the same power is larger than if no such spring is inserted. The cause of the increase of effect may be accounted for in the sudden closing of the valves, which admits of no loss through these, and in the sudden impulse given to the piston, which at once imparts that motion to it which is in accordance with the motion of the water in the pipes. A piston-rod ought to be elastic; it should commence its lifting motion with a sudden jerk, and give way to the motion of the water, so that the latter may not be forced to vary its motion in the same stroke. In a suction-pump, the proper arrangement is to suspend the pump-rod on a spring; if we press the pump-rod down to its lowest point, and then cease all action upon it, the spring will return suddenly, and lift the water. This is the principle applied in working steam-pumps, such as are used in mines. The beneficial effect of this arrangement is, however, more sensibly felt in hand-pumps, as may be easily proved by appending a spring-pole to a hand-pump, depressing the piston by hand, and ceasing the action upon it when in the lowest position. The water raised in this manner is by far more than by the common lever, and incomparably greater than that raised by the motion of a crank at the same pump. The speed of the piston is too great, and a pump will not suck at all if that speed is greater than the velocity with which water flows into a vacuum.

The form of valves and pipes has a decided influence

upon the effect of a pump; all bends in the pipes must be avoided, and the valves must in all cases be so constructed, that the course of the water may be as straight as possible. The suction-pipe may be narrower than the cylinder; but it ought to be a straight prolongation of that part. The force-pipe also is best when a prolongation of the cylinder, with the piston-rod moving in the centre of it.

For the reasons we have given, single pumps are preferable to double-working pumps, because in the latter the current must be more or less curved, to make room for the stuffing-box and piston-rod. It is highly disadvantageous to force back the contents of a cylinder; that is, if both the suction and the force valve are at the bottom of the cylinder.

THE QUANTITY OF WATER RAISED IN A PUMP

Depends very much on its construction. If a pump is in good order — that is, if its valves close perfectly, and the packing of the piston closes tightly on the cylinder — the quantity raised is equal to the surface of the piston multiplied by its stroke, minus the quantity which passes through the sleeping valve before it is perfectly shut. This result is not commonly reached; the valves never shut tightly, and the packing of the piston cannot be expected to be hermetically tight. The loss in large, but well-constructed pumps, may be one-tenth; in smaller pumps, two-tenths; and in hand-pumps, four-tenths. The slower the motion of the piston, the greater is this loss; we find, therefore, that badly-leaking pumps must be moved very rapidly, to afford an adequate supply of water.

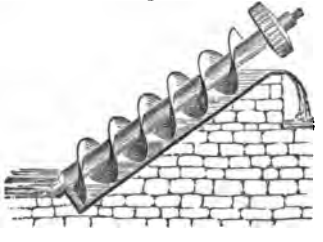
ROTARY PUMPS.

Frequent attempts have been made to construct rotary pumps, but they have been more or less failures, affording less effect, from a certain amount of labour, than the cylinder pumps. In principle there are elements which favour these pumps, particularly the absence of valves, and a permanently equal motion of the water; but there are practical difficulties which appear to defeat their success.

ARCHIMIDEAN SCREWS.

These machines are not of much interest as a means for raising water, but we shall pay some attention to them on account of their being used as propellers on steamboats. If we wind a flexible pipe around an axis or cylinder, and incline this axis to the horizon, and revolve it, in the mean time dipping the lower end below water, the water will rise in the pipe, which forms the thread of a screw, and it will be discharged at the highest part of the screw. On the same principle we may wind a solid thread around an axis, and form a screw, if we move this screw around its axis, it being in the mean time inclosed in a cylindrical casing; the action of the latter screw is similar to the first.

Fig. 78.



In fig. 78 such a screw is represented. It is not necessary here for the casing to reach all around the screw. If the trough formed by the casing is large enough to hold the water raised, which forms a kind of steps, it is all-sufficient. The absolute effect of these machines depends upon so many elements,

that a calculation of it is unsafe, and not to be relied upon. A screw of this kind, on trial, afforded the following results:

Number of revolutions per minute.	22,	41,	49,	51,	74,	121.
One quantity of water in times.	146,	85,	71,	72,	53,	39.
Quantities of water in one revolution.	15·7,	14·9,	14·6,	14·1,	13·1,	10·9.

When a screw is turned too fast, it ceases to afford any water. The figures in the foregoing table allude to a pipe-screw; the quantities are from 12 to 15 per cent. less in an open screw, imbedded in a trough. The effect of a pipe-screw is therefore, in all cases, preferable. In the screw represented in the drawing, nothing is required but to cover the threads by a permanent cylinder, which moves round with the screw, to convert it into the first. The pipe thus formed, by joining thread and inclosure, must be as smooth as possible. In constructing such a screw, a great deal depends upon the inclination of the thread, and the depth to which the screw dips into the water at its base. The pitch of the screw to its inclination must be so that the screw may hold the largest quantity of water, and also that it does not flow out all together. It does not make any difference in the effect if but one thread, or more, are submerged; the screw will absorb but a certain quantity of water, provided it is supplied in sufficient quantities at its base. For raising impure water also the pipe-screw has an advantage over the open screw. The inclination of a screw is generally 45°, or as low as 30°, in open screws.

A question of considerable importance in this case is, with how much force the water in a screw will strive to turn the screw around its own axis, by its inherent force. The case is here, as in all other questions of mechanics, that the force and resistance are equal; there is no loss in the screw, provided certain conditions are complied with

Actual experiments with screws three feet in diameter, have shown that a screw whose thread is in an angle of 60°, is the most profitable for raising water. If the quantity of water raised by a screw-thread of 60°, and 30° inclination, is called 1, the degrees noted in the following table belong to the inclination of the same screw, for raising water, the screw being 18 feet long, to one foot in diameter, making 90 revolutions per minute.

Angle of inclination.	30°,	35°,	40°,	45°,	50°,	55°.
Quantity of water raised.	1,	·93,	·74,	·50,	·31,	·10.

According to general rules a screw ought to raise water in a ratio to the cube of its diameter; but this is not the case, and practice shows that it rises more rapidly, or $D^{3\frac{1}{2}}$, if D is called the diameter.

From the foregoing we see the importance of the inclination of the thread as well as the shaft, and the bearing of the diameter. We see also how exceedingly difficult it is to establish a general expression for the resistance to motion, in a screw; for this operation sufficient experiments have not been made. We may arrive at a result sufficient in practice, by basing upon the facts as stated above. All the above experiments allude to the pipe-screw. An open small screw, inclined 30°, or that angle by which it furnishes the largest quantity of water, made the subjoined number of revolutions per minute, and the annexed quantities of water:

Number of revolut'ns.	43,	52,	90,	101,	124,	159,	190,	195,	220,	270,	321.
Quantities of Water.	1·07,	1·66,	2·72,	2·96,	3·33,	3·60,	3·51,	3·42,	3·02,	2·61,	0·89.

The inclination of the thread to the axis was about 50°. By this we perceive that 159 revolutions produced the greatest effect; and as the height of one thread was three inches, the velocity of the water in the screw, paral-

lel with the axis, was not quite three-fourths of a foot per second.

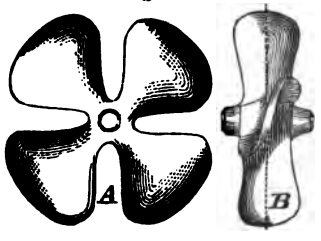
The greatest loss in these open screws is that which is caused by leakage between the threads and the enclosure, which, in small screws, amounts to 12 per cent. more than in the pipe-screw, and which, it may be assumed, is the same in large screws as in small ones. An important cause of loss in the open screw is the height to which the water is raised; and if the above alludes to the loss in one second, and the water remains longer than that in the screw, the time multiplies the loss. For these reasons the pipe-screw is preferable to the open screw; but the case is altered when the end of the screw dips deeper into the pond, or the water level is variable, for in these cases the open screw is preferable to the other.

If P is the weight of water in a screw, or what is the same, the height derived from the velocity, is times the weight, there is equilibrium in the screw when P is equal to the angle of the thread, and the surface of the circle. This law, however, is modified in every particular instance.

SCREW PROPELLERS

Are Archimidean screws, in an unlimited amount of water. In fig. 79, A represents an elevation, and B a section. If such a screw, which is generally made to consist of four blades, is fastened to the stern of a vessel, and revolved about its axis, it will propel that vessel with a certain velocity, according to the size, form, and power applied to the screw. To

Fig. 79.



determine the form of a screw propeller, in a particular case, is a difficult task, because it does not depend only upon the form and speed of the screw, but in a great measure on the resistance of the vessel which it is to propel; and as the resistance of two similar vessels is not necessarily the same, the form of the screw is difficult to determine, in a particular case. A certain form of the blades of a propeller is perfect only in one instance, that is, for a certain number of revolutions, and the way they move during one revolution. If one of these conditions is altered, the form of the blades is incorrect; they are also affected, in the same vessel, by a large or small load, the direction of winds and currents, and the speed of the engine. It is therefore out of the question to make a propeller which is perfect, in all cases; and all we can do is, to come as near to it as possible.

If we consider this screw as the former open screw, with the difference of having an enclosure all around it, but not fastened to it — the same form as a smoke-jack — and if we apply a current of water to the vanes, the number of revolutions does not increase with the velocity of the current, nor does it increase at a rate which may be determined by experiment; so that a coefficient, a, cannot be settled upon. It will require a number of experiments for each particular velocity of the current, and these experiments will form a series of coefficients which may be applied in each case. Each case is therefore a practical case, and requires a particular investigation. From this it is evident that a useful theory of the screw propeller is difficult to establish. If we consider this subject in general forms, we may, however, approximate a construction, which, if not perfect, is at least useful. The screw turned around its axis will press a certain amount of water through the spaces between its

blades; this water ought to move in a direction parallel with the axis. To do this, it is required that the form or inclination of the thread of the screw should be in proportion to the number of revolutions. In bringing the water in contact with the blades, the latter will move it parallel to the axis, and also in a radial direction, and throw it by centrifugal force against the enclosure: if no enclosure is around the screw, it will cause a swell which will rise until its pressure is equal to the centrifugal force. A loss of labour is therefore inevitable by this radial motion. The centrifugal force increases with the square of the speed, and the propelling force inversely as that speed; in driving a screw, therefore, faster than is calculated for, a great loss of labour must ensue. If the enclosure is not fastened to the screw, the direction of the current will be always parallel to the axis, provided the enclosure is at least as long as its diameter; a loss of power is here sustained, in consequence of the friction against the enclosure. If the parallel motion of the water with the axis could be sustained for the whole diameter of the screw, no loss could be caused by centrifugal force; this may be attempted in constructions, but it is not possible to realize it. Another cause of loss is that of velocity at and near the axis of revolution; the propelling power cannot be as great here as near the circumference. This evil also may be modified by the form of the paddles; but it cannot be entirely removed.

The quantity of water passing through the screw in its revolutions is the measure of its labour; this depends on its diameter, (and it increases faster than the square of the diameter,) on the number of threads or blades, and on their inclination. An inclination of the blades to the axis of 50° works the most advantageously, as has been proved by

experiments; but this ought to be more at the axis, and less at the periphery. If a propeller would furnish a vein of water equal to its section, and with uniform parallel velocity in all its parts, its propelling power would be equal to that quantity, and it is equal to the quantity actually moved in a parallel direction with its axis.

LIFTING OF WATER BY MEANS OF BUCKETS

Is a profitable application of labour, if the height to which it is raised be not too great; it answers a good purpose, if the men performing this labour are not compelled to move their bodies too much. In the latter case, but little effect is obtained. If the height to which water is to be lifted is greater than a man can conveniently reach, a scoop, to which a lever or chain is attached, may be used. In still higher elevations, it is more profitable to employ buckets and a whin, if pumps cannot be used; in this case, the wheel with spokes, for the purpose of turning the shaft, is preferable to the crank. All other machinery for lifting water is inferior to the pump.

MOTION OF AIR AND GAS.

The quantity of air or gas discharged from an aperture of a vessel in which the pressure is greater than the surrounding pressure, is in relation to the difference of pressure; or, what is the same, the height of the column of air or gas. The velocity with which air is discharged, is $V = \sqrt{2 \times g \times h \times \frac{D}{D_1}}$, in which formula V is the velocity, D the density of the enclosed, and D_1 the density of the external air; the other letters are known. The velocity, multiplied by the section of the aperture, furnishes

the quantity of air discharged. In these calculations the temperature of the different gases is to be considered, not only so far as it influences their density, but also in its facilitating the motion or flow of the gases; the latter will increase the quantity discharged, if a difference of temperature exists between the enclosed and the external air. For the increase of velocity by this cause, no coefficient has been determined upon, and it is at present left to the option of the operator. The form of the aperture must be considered in all cases, and we have here, as well as for water, a coefficient of contraction. For an aperture with thin sides, such as sheet metal, the coefficient is ·65; in cylindrical pipes or mouth-pieces, it is ·92, if the mouthpiece is not over ·6 inch long; a pipe six inches in length diminishes it to ·83, and a twelve-inch pipe to ·73. If the pipe or mouth-piece is tapered, the coefficient is not much altered; it has, in fact, but little influence, provided the pipe is smooth; and in most cases ·92 will be correct. If the pipe is much tapered, the coefficient is diminished; if the angle of the pipe is not more than 12°, the coefficient increases to ·94. We may, therefore, in the majority of cases, employ ·65 for thin sides, as sheet metal; ·93 for cylindrical mouthpieces; ·94 for nozzles of not more than 12°, and ·92 for nozzles of more than 12°. In this case, the formula for the efflux of gases will be, if S is the surface of the aperture, C the coefficient of contraction, and C_1 the coefficient of increase by difference of temperature,

$$Q = S \times C \times C_1 \times \sqrt{2 \times g \times h \times \frac{D}{D_1}}.$$

In determining D and D_1 in this formula, it is necessary to resort to the manometer; and in case the efflux is into exhausted vessels, the barometer is used to determine D The calculations in these cases are simple. If the mano-

meter is filled with mercury, we are to multiply the height of the column by the difference in the specific gravities; or, in other words, the height of the column of mercury, and that of the gas, are inversely as their specific gravities.

It does not make any difference in this operation if the gas is atmospheric air, steam, or any other gas, if we only exercise proper care in observing the densities. If the quantity of efflux of one kind of gas is determined, and its density noted, we may find the efflux of other gases; for the quantity of gas discharged from equal apertures, under equal pressure, is inversely as the square roots of their densities.

MOTION OF AIR IN PIPES.

If gas is conducted in pipes, its velocity is increased, which diminishes its density. Gas is highly elastic, and its particles compressible. Where the densities are greatest, the velocities are smallest, in a pipe; and as the densities decrease, the velocity increases, because there cannot be as many atoms in an expanded as in a condensed form. The decrease of density is in proportion to the length of the pipe; and as the velocity increases with the decrease of density, it will of course increase with the length of the pipe. This is a different law from that of water in pipes, and applies only to gas in motion; it arises from the elasticity of the gas. This explains why the coefficient of friction for gas is a permanent figure. The loss in density is considerable in narrow pipes, and is in proportion to the density of the gas and the length of the pipe — two causes of loss which we shall determine hereafter.

The quantity of air discharged by an aperture depends, in addition to the above causes, on the height of the barometer and thermometer, and the quantity of aqueous

vapour in the condensed air; it is also influenced by other causes, but these, for practical purposes, may be neglected. If precise results of efflux are required, it is to be remembered that the specific gravity of air, compared with water or quicksilver, is not a permanent number. For common purposes, we may adopt the number 772 as expressing very nearly, under a certain condition, the weight of a volume of water to that of atmospheric air. In all cases of practical investigations at blast-machines, it is necessary to bring the manometer as near as possible to the nozzle, and apply the above formula, which will very nearly give the quantity of air discharged.

In respect to pipes, all the laws relating to water-pipes are applicable here, with due consideration of velocities. The influence of knees and bends in conducting air through pipes is very great; contractions also are injurious to the densities.

IMPULSE OF AIR.

Air in motion will produce a certain effect upon a body it may meet with in its course; it does not make any difference whether the air or the body is in motion. In common or low velocities, the resistance increases with the square of the velocity; in great velocities, such as cannon-balls, the resistance increases more rapidly, but is not equal to the cube of the velocity. The force of impulse upon a plane surface may be considerably increased by raising an elevated border around the plane, or making the surface concave, such as the sail on a vessel. The depth of the concavity should never be more than one-fourth of the width of the plane, or the advantage resulting from it is lost. The resistance of gas to motion is in proportion to its density; we have therefore to consider velocity and

density. We can apply here the formula relating to water, if we consider that the density of water is permanent, and that the density of atmospheric air changes with the height of the barometer and thermometer, and the quantity of moisture. All other laws relating to water may be applied here with the above modifications, and will be found not far from the truth.

THE OBLIQUE IMPULSE,

Or the impulse of air against an inclined plane, is subject to similar laws as those applied to water. The resistance is but little diminished on thin planes, such as sails; it does not amount to more than a very slight per centage. If air is propelled against a double inclined plane, such as a wedge or a corner of a prism, a cylinder or a globe, the amount of pressure is greatly diminished. If the pressure upon a square surface is counted one, then the pressure upon a square prism of equal surface, and

a corner of 90°, will offer		·728	resistance.
A prism of 60°,	"	·520	"
A wedge of 90°,	"	·691	"
" 51°,	"	·433	"
Half a cylinder,	"	·570	"
A sphere,	"	·410	"

VAPORIZATION.

After the cohesion of ice has been suspended by heat, a further accession of that force will convert the liquid water into steam. The repulsive force set in action by the agency of heat will cause the particles of water to fly from each other, and they will only be restrained by surrounding matter from dispersing indefinitely into space. This law applies, not to water only, but to all matter. The force

exerted by the repulsion of the particles upon the surrounding matter, is measured by the pressure which it exerts upon that matter. Every liquid has, under the same circumstances, one specific point at which it invariably boils, or, what is the same, forms steam or vapour. Pure water boils at 212°; alcohol of a specific gravity of ·813, at 173°; ether at 96°, and lead at or near 1000°. Iron may require a heat which it is not in our power to produce. These points of heat by which the various matters evaporate, refer to the atmosphere as the surrounding medium; if the evaporating matter is enclosed in a metallic or other vessel, and the vapours prevented from escaping, the point of ebullition rises with the pressure exerted upon the surrounding vessel. If the vapours are extracted from the vessel more rapidly than the heat finds access to the fluid, the boiling point is considerably reduced, or the evaporation accelerated. This principle is employed with sugar-pans, to make the syrup boil at a lower degree of heat, because it is injured at a temperature of 212°. The same principle acts in the condenser of a low-pressure steam-engine. It makes no difference what matter confines the steam, whether air or iron; the same law applies in all cases. If steam is confined in a steam-boiler, its pressure on the sides of the boiler will augment with the accession of heat; if the water or steam confined shows 250·5° on the thermometer, the pressure from the inside to the outside will raise a column of quicksilver thirty inches high, or one atmosphere. If there is an aperture at the boiler through which the steam may escape as fast as it is generated, the steam will never rise above a temperature of 212 degrees.

LATENT HEAT OF STEAM.

In heating water and converting it into steam, a large quantity of heat is absorbed, which is not shown by the thermometer; it becomes latent, and is given out again in condensing the vapours. The best experiments on this subject have shown that the latent heat of vapours is between 900 and 1000 degrees; that is, water converted into steam absorbs not only 212°, but it absorbs 900° more, though it shows only 212°. One gallon of water converted into steam will, by condensation, raise the heat of five gallons of icy water to the boiling point, or 212°; but it will form no steam at this rate.

DENSITY OF STEAM.

The weight of a given volume of steam increases directly as its elastic force; this is a general law for all gases, as explained in former pages. The same weight or quantity of steam contains in all cases the same quantity of heat; its latent heat being increased as its sensible heat diminishes. If a certain quantity of steam is confined in a cylinder, under the pressure of a piston, and we reduce the space it occupies by pressing the piston upon it to half its original volume, without condensation or cooling, it is evident that in this case the amount of heat in the expanded or condensed state of the steam must be the same; the latent heat will diminish, and the sensible heat increase. If we reverse this experiment, and expand the original volume of steam to double its size, by raising the piston; the density will diminish, the sensible heat decrease, and, provided no heat can escape, the latent heat must be increased. The sum of both latent and sensible heat, therefore, in all cases, remains unchanged. This law holds good with all vapours.

FORM OF APERTURE.

If steam, or any other gas, issues from an aperture into the air, or any other cold medium, it will penetrate further into the air, if in a cylindrical column, than if issuing in a conical form, or in a turbulent manner. In the latter case, the elastic fluids immediately become mixed; while in the former, the compact motion retards that mixture. This law, so generally known and of such extensive application, is of particular importance in the construction of chimneys.

CHAPTER VII.

MECHANICAL EXPEDIENTS.

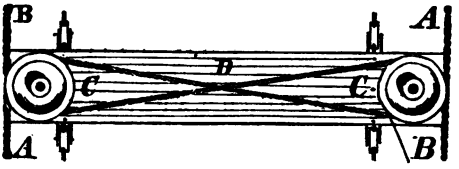
MOTIONS of various parts of a machine are performed according to certain rules, and depend on the forms of these parts. We shall endeavour to show how such motions are regulated, and by what means. This subject may be conveniently divided into several parts, such as parallel motions in straight and curved lines, oscillating motions, rotary motions, &c. It is our object to show the conversion of a certain given motion into another.

MOTION IN A STRAIGHT LINE

May be continued in that line with the same or an altered velocity. When a rope works over a pulley, its motion is continued with the same velocity, but in a different direction; if it works about more than one pulley, its motion is also in a straight line, but in a different direction,

and with an altered velocity. A straight line may be moved parallel with itself by moving two triangles, one along the other, or by using the generally known parallel rule which is appended to almost every case of drawing instruments. Another parallel motion of a straight line is the counting-house ruler; in this there are two revolving cylinders, which by their revolution cause a parallel motion. The most ingenious contrivance for the production of a straight line parallel with itself, is that generally employed in mule-spinning machines, for imparting a parallel motion to the carriage. If two strings, fig. 80, are fastened to the four

Fig. 80.



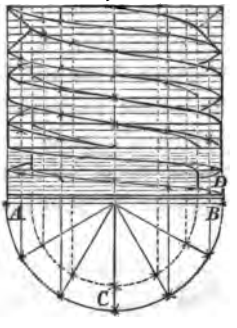
points, A B and B A, and slung around the rollers C C, and the carriage D, and D is then set in motion upon its four wheels, its motion will be perfectly parallel, provided the strings are of equal tension. The same motion may be produced by putting a shaft along the carriage, and two pinions and racks, one at each end. If the weight of the carriage is considerable, and the wheels and rods are of much adhesion, such as between the iron wheels of cars and locomotives, and the rails of the road, a perfect parallel motion may be obtained by mere friction, provided the shaft connecting the wheels is so strong as not to twist, and cause by this a difference in the motion of the wheels. The friction of such wheels may be increased by counter pressure, in case the pressure upon the wheel itself cannot be made strong

enough; this counter pressure is produced by an opposite wheel, which presses the other side of the rail. These two wheels, touching the rail on opposite sides, may be made to adhere by screwing them more or less closely to the rail.

STRAIGHT INTO CIRCULAR MOTION.

This conversion, and the reverse of it, is of very extensive application. All water-wheels may be considered as a means of converting a straight into a rotary motion; so also a rope slung around a cylinder or pulley, a chain or belt working a pulley, and a great number of other motions. The screw, in being turned around, moves its nut in a straight line; and the screw propeller of a steamboat converts its rotary motion into a straight movement. In the latter case, the construction of the screw-line upon a plane is one of the elements of its mechanism, for which reason we will show that construction.

Fig. 81.



If, in fig. 81, AB is the diameter of a screw, we draw the semicircle ABC to it, and divide it into a certain number of equal parts. Half the pitch of the screw BD is divided into an equal number of equal parts, and then the dotted lines drawn from the points of division in the circumference parallel to the axis of the screw; where these lines cut the lines which divide the pitch of the screw, there are the points in which the screw-line must necessarily fall.

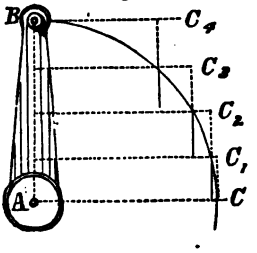
THE CRANK.

This is one of the machines most generally in use for converting a longitudinal into a circular motion. The

question has been frequently raised, whether there is not a loss of power connected with the use of the crank; and many machinists doubt whether there is a full transfer of the power imparted. It is an absurdity to doubt the full transfer from the crank on general principles; for no power can be lost in any case, and particularly not where rigid matter acts upon rigid matter. The only loss known is absorbed by friction; this is a coefficient of loss in the crank, as well as in all other transfers of force; and the only rational question as to the loss of power in the crank motion, is the loss by friction.

Those who are inclined to investigate this matter, may divide the circle described by the crank into certain parts, and form a polygon of it. In drawing parallels with the diameter, which represent the acting force, through the points of division, and also perpendiculars upon those parallels to the points, an indefinite number of parallelograms may be formed, to which the circle forms the diagonals. In comparing the sides of these parallelograms, and converting them into forces, it will be found that their sides in every particular instance are equal to one another, which of course makes the diagonals equal; that is, the same force is exerted upon every part of the circumference. In this instance, we neglected the oblique action of the connecting-rod; but if we apply the same rule here as to the crank, we shall find no loss of power. Or, if we are not convinced with that argument, let AB (fig. 82) be the length of the crank; and if the force F acts upon the point C, and of course F moves with uniform velocity, it

Fig. 82.



will move C to C_1 in one-eighth part of a stroke, or half a revolution; in the second part it will move to C_2, in the third to C_3, and in the fourth to C_4. We find, in comparing the diagonals to these various parallelograms, that their lengths are inversely as the force. In theory, therefore, there is no loss of power; but such may happen in practice, as we shall show hereafter. If the linear motion is uniform, and it operates upon a crank, the motion of the crank-pin cannot be uniform; its velocities will be inversely as the diagonals represented in fig. 82.

There are various other movements which convert a linear force into a circular motion, such as a ferry-boat crossing a river by being fastened to a point in that river by means of a long chain, and other contrivances of a similar nature.

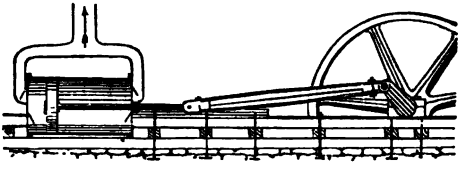
If a straight linear motion is to be converted into a curved linear movement, it is generally done by converting it first into a circular motion, and that into the required curved motion. So, if the returning or oscillating linear motion is to be converted into progressing linear motion, it is first converted into rotary, and then progressing motion.

THE ROTARY MOTION

Of a uniform speed, or a speed regulated by certain laws, may be converted into linear motions of uniform or irregular speed. If the crank-pin moves with an uniform speed, the linear motion into which it is converted is not uniform; it is inversely as the diagonals in fig. 83. In this case, a loss of power may be experienced by the crank. If the piston of a blast cylinder is moved by a water-wheel, the force exerted upon the piston will be greatest at the dead points of the crank; the water-wheel will move with an increased speed, and, in consequence, lose power. When

the crank is moved one-quarter of the circle, the force exerted upon the compressed air is checked, and the speed of the wheel reduced. This variable resistance causes an

Fig. 83.



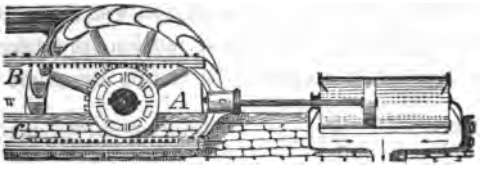
irregular speed in the water-wheel, and consequent loss in power. In this case we find still more loss of power than that arising from the irregular motion of the wheel. If, at the circumference of the water-wheel, there is an active force like water, that force will be increased in the crank, should the circle which the latter describes with its pin be smaller than the first, and diminished if larger, in proportion to the lengths of the circumferences. The active force exerted by the crank is, however, not more than two diameters, in the best case; that is, if no effect of the water-wheel is lost by the irregular motion. The oscillatory motion of the piston meets in every part of its way a certain resistance, which is in this case the pressure of the blast. In the middle of the stroke, or when the crank is at right angles with the direction of the linear motion of the piston, the resistance may be assumed to be equal to the force. If we need a certain density of blast, we are under the necessity of constructing the water-wheel and crank so as to produce that density when the piston is at its highest speed, or at right angles to the piston-rod. The resistance is here regulated by the nozzles of the blast-pipes, and is as the piston's motion; and as the moving

power may be assumed to be uniform in its circular motion, it cannot increase the pressure of the blast, because the velocity of the piston is a condition necessary to increase that pressure. The latter cannot be realized; on the contrary, it diminishes gradually to the dead point of the crank, and increases from there in its return motion. We experience here a real loss in power, in the proportion of $2 \times D$ to $3{\cdot}1415 \times D$, or two diameters to the circle described by the crank-pin, irrespective of the loss by irregular speed in the water-wheel.

THE HALF-TOOTHED WHEEL.

The loss of power in the crank, in converting rotary into linear motion, is still more apparent if we compare it with the half-toothed wheel. In fig. 84 is a blast-cylinder, and

Fig. 84.



a conversion of the rotary motion represented, which is theoretically more perfect than the crank, but is very limited in practical application. The half-toothed wheel A, fastened to the axle of the water-wheel, will transfer the whole force of that wheel to the two racks B and C, and the piston-rod. Here, two lengths of the stroke are equal to the periphery of the cog-wheel and its velocity; consequently, no power is lost. If in both cases, that of the crank and this wheel, we have an equal power in the water-wheel, the pressure of the blast will be remarkably

greater in the latter than in the first case. If the force in the buckets of the water-wheel is equal to 1000 pounds, and if the way travelled by the piston of the blast-cylinder is to the way travelled by a point in the circumference of the wheel as one to ten, the pressure of the piston upon the air before it is ten times as great, or 10,000 pounds, minus friction and other losses arising from dead space. If we apply the half-toothed wheel for producing the linear motion, this is correct; but not in the crank. If the water-wheel is eighty feet long in its periphery, it requires four feet stroke, or eight feet motion of the piston, to make one-tenth of the way of the water-wheel. This length of stroke may be produced by a half-toothed wheel of eight feet circumference, or a radius of $\frac{8}{2 \cdot 314} = 1 \cdot 27$ feet. To impart that motion to the piston, it requires a crank of two feet; and as the pressures of the piston upon the confined air are inversely as the radius of the water-wheel to the radius which produces the linear motion, the pressure of the piston moved by a crank will in this case not amount to more than $\frac{10{,}000 \times 1 \cdot 27}{2} = 6350$ pounds, instead of 10,000 pounds. And if the surfaces of the pistons are in both cases the same, the densities of the compressed air will be as these numbers.

If we consider the connecting-rod, in this instance, which belongs to the crank, the result is still inferior to the above, for the oblique action of this rod is here disadvantageous. If there is no loss of power in the crank by converting the linear into a rotary motion, there is certainly a loss in converting the rotary into linear, in most cases.

The form of the half-toothed wheel, in converting motion, is perfect in all instances, but its application is very

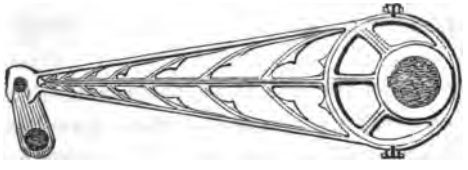
limited. At each end of the oscillating linear motion there is a moment of disconnection between the driving power and the driven machinery; this causes an increase of the velocity of the driving and a decrease in the resisting power, which causes a sudden shock or concussion between the parts of the machinery. This concussion is destructive to the machine, in case it is violent, that is, if the motions are rapid: weight, and particularly velocity, are here to be avoided. A practical speed for a blast-cylinder may be one, but not more than two revolutions per minute; no cast-iron machine will resist more than that speed. The durability of a machine, in this instance, may be greatly increased by making the time of disconnection as short as possible.

The loss of power in the crank may be obviated, in this and similar cases, by multiplying the number of cranks. Two cranks are qualified to impart more power than one, and three will yield still better. The laws developed above apply but to one crank.

THE ECCENTRIC

Is another means of converting a circular into a linear motion. The common eccentric (fig. 85) is generally ap-

Fig. 85.



plied where a crank is not practicable; it performs the same motion, and is subject to the same laws. As a me-

chanical expedient it is inferior to the crank, because it causes far more friction. The throw of an eccentric is equal to twice the distance between the centre of the shaft and the centre of the eccentric. The speed of the linear motion is irregular in this case; it is greater in the middle of the stroke than towards both ends. This eccentric is extensively used in steam-engines for moving sliding valves. It is a practical machine for this purpose, however incorrect in principle. A loss of power is the consequence of its slow motion at both culminations.

ECCENTRIC FOR REGULAR LINEAR MOTION.

If a regular linear oscillating motion is required, we may produce it by various means; one of the most common is the heart-shaped eccentric. In fig. 86, that motion is represented. If a plane circle moves about its axis with uniform velocity, and the distance, AB, is to be travelled twice in one revolution, in equal times, with uniform speed, we make CD = AB, and divide the space, CD, into equal

Fig. 86.

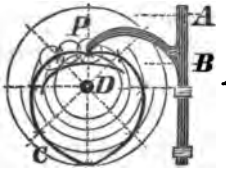
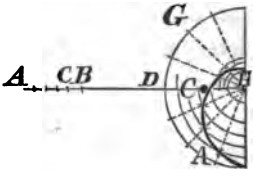


Fig. 87.



parts; draw circles through these parts, and divide them into twice as many equal angles; then draw the radius, and where the radius and the circles cut each other, there is the line in which the point, P, is to move to form the desired motion. If in this instance a roller is used, as indicated by the dotted lines, partly to diminish friction and

partly to prevent abrasion of the moving parts, the size of the roller to be applied is taken, and a series of circles described, whose centres are in the curve drawn at first; by drawing the tangents to these circles, the curve is arrived at in which the roller is to move, to perform the desired motion.

IRREGULAR ECCENTRIC.

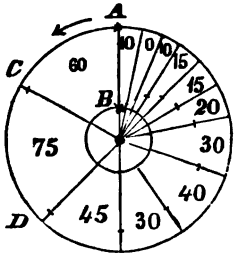
To produce irregular motions, that is, to convert a regular rotary motion into an irregular linear motion, the following means may be employed. Fig. 87 represents an axis, and AB the distance of a linear motion, to be travelled over twice in every revolution; the time in which this is to be performed is one revolution of the wheel. If we want the distance from A to C to be travelled over in one quarter of a revolution, and that with uniform velocity, AC is to be equal to DC, and all the equal parts between AC must correspond with equal parts in DC. To arrive at this we divide the space, DC, into corresponding parts with AC. In drawing the circles and radius, the crossing points of both are the direction of the curve. If the space, CB, is to be travelled through in the second quarter of the revolution, we again divide DG into equal angles, and GH into equal parts, and obtain here the other part of the curve. If the linear motion from B back to A is to be performed in a similar manner, or reversed, as from A to B, the other half of the circle is constructed accordingly.

ANY KIND OF MOTION

May be performed by an eccentric line moving round a centre with uniform angular velocity. If fig. 88 is a circular motion, and we want to convert it into a certain linear motion, of any curve or velocity, we solve the problem generally, by making the angles of revolution equal

to the space to be travelled. If one revolution is performed in twelve seconds, the space to be travelled is or may be 2 × AB; this space may be divided into arbitrary or chosen parts, each corresponding to one time, or one second. These parts are laid upon AB, six from A to B, and six from B to A. On drawing circles through these divisions, and also radies corresponding to twelve equal parts of the circle, or what is the same, dividing the circle into twelve equal angles, the crossing points are the direction of the curve.

Fig. 88.



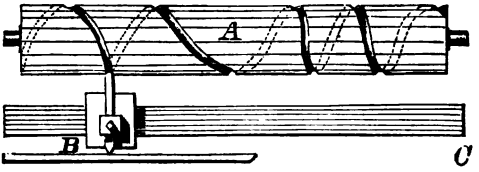
The angles of revolution are also inversely as the times of the linear motion, and as the spaces of that motion. We divide the space AB into twelve, or more or less equal parts, and draw circles through them. The circle is then divided corresponding to the spaces, and not into equal angles. If the space AB is divided into 360 parts, corresponding to the degrees of a circle, this would make 30 parts to every second of motion; but we want 60 parts in the first second: this will make one-sixth of a revolution, and the point A arrives at C in the first second. The second time, or second, 75 parts shall be travelled; we take, therefore, 75°, and arrive at D. The third second, 45°; the fourth, 30°; the fifth, 40°; the sixth, 30°; the seventh, 20°; the eighth, 15°; the ninth, 15°; and the last three, each 10°. We arrive here at a sudden stop, or, what is equal to it, the space BA is to be travelled in no time, which is an impossibility. We are therefore, in practice, compelled to provide some time for the returning motion. These motions are not confined to a plane revolv-

ing around its centre or axis; they may be constructed upon revolving cylinders, with equal facility and correctness.

REVOLVING CYLINDERS

Are more qualified to impart variable motions than revolving planes. If the cylinder A (fig. 89) revolves with a certain known regular or irregular velocity, we may pro-

Fig. 89.



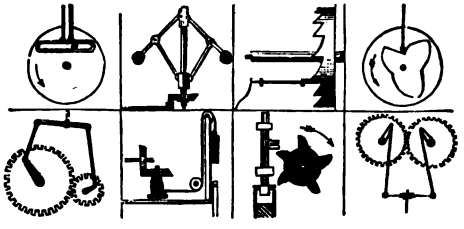
duce in the slide any kind of irregular or regular motion, in the direction of the rail or guide CB. We divide the circumference of the cylinder into equal angles, and draw lines parallel with its axis over its surface. The length of the cylinder is now divided into parts corresponding to the motion we intend to impart to the slide B; this may progress in any manner we choose. In drawing parallel circles in these divisions, we obtain the crossing points which form the curve; this curve is cut into the cylinder, and forms the guide for a pin fastened to B. If in B a sharp bit of steel is fastened, and a plane moved against it, either with a regular or irregular velocity, a linear or rotary motion, or any figure we choose, may be described upon that plane.

This subject may be indefinitely extended, if no other object but variety of motion is expected; the theoretical part is inexhaustible, which however in practice is not so; many motions, particularly sharp angles, are difficult tc be executed correctly.

A VARIETY OF MEANS

Is afforded for converting rotary into linear motion; those represented in fig. 90 are generally in use, and are

Fig. 90.

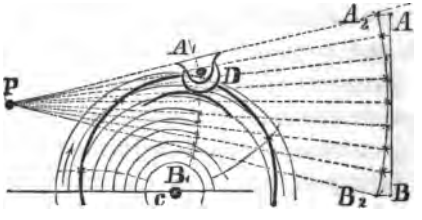


easily recognized. Before leaving this subject, we shall allude to two more motions of this kind, on account of their extensive application.

AN ECCENTRIC MOVING A LEVER.

This is a case of frequent occurrence, and is particularly used in connection with spinning machines for setting the bobbin-rails of throstles in motion. We shall not allude to a particular case, but consider the question generally.

Fig. 91.



If, in fig. 91, the space AB is to be traversed twice while the axis C makes one revolution, and if the motion is to be

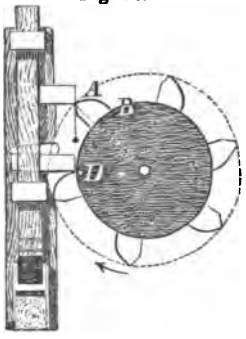
equal spaces in equal times, we divide it into so many equal parts; if it is to be traversed irregularly, we divide it into as many unequal parts as are moved through in equal times. These parts are transferred by the lever ADP, taking the three parts—that is, where the lever is fastened, the centre of the friction roller, and the hole at the other end—as the points forming the lever, which in this, and in most other instances, form the two sides to a triangle. The divisions in AB are transferred rectangularly upon the linear motion to the arc $A_2 B_2$, and, in moving the lever over the space which it is to traverse, mark the points of division on the circular plane which has the axis C to its centre. $A_1 B_1$ is by these means divided into corresponding parts with AB. If we now draw circles from the centre C through the points of division in $A_1 B_1$, and divide the largest circle into as many parts as are contained in 2 AB, we obtain, in those points where the arcs drawn with the radius PA cut the circles, the elements for the curve. If a friction roller is used to glide over the curve, we describe, from the curve constructed for the centre of that roller, a series of circles equal to the roller in diameter, which, in drawing the interior tangents, furnish the curve sought for. In these constructions, only one particular case is admissible; if any one of the points A, B, or its divisions, D, P, or C, is shifted from its place, the case is altered, and the motion in AB is not that which it was intended to have.

TAPPETS, CAMS, OR WIPERS.

Another case of this kind we intended to allude to, is that of tappets in stamping machines, tilt-hammers, and similar cases. If a revolving axis is to produce a lineal motion, such as stampers, which are lifted vertically and

return by their own weight, we generally construct the form of the tappets so as to produce a uniform motion, or in many instances an accelerating motion, in the stamper.

Fig. 92.



In fig. 92 is a representation of a stamper, with its shaft. The weight of the stamper, and the lift, size, and number of cams, must be decided before the form of the curve can be determined upon. In drawing the stamper upon a board, we mark the length of the counter-wiper D, and also the lift, and draw two circles, A and B, through each point. Assuming the counter-wiper to be a straight line, we have to draw a curve for the wiper between the two circles A and B. In drawing the radius AC, we obtain the length of the tappet, and a plumb-line from A will give the form to its back. We describe, for obtaining the curve of uniform motion, an evolvent to the circle B, from the point D, which is the right angle to the rectangular triangle ACD. By moving the line AD, which may be a string fastened in D, over the space between the two circles, and laying the string on the circle B, we obtain the curve by scribing with the point A. To draw this evolvent in practice, it is necessary to have a perfectly round board, or a part of the circle B.

If it is desired to move the stamper with irregular speed, either accelerated or retarded, we divide AD into such irregular parts as the motion is designed to be. We now draw an evolvent to each part of that circle which falls together with the points of division in AD. The connection of the points thus obtained forms the desired curve. These curves of the wipers are easily destroyed in prac-

tice, because they are rubbed off gradually. This might be prevented by putting a friction roller in the counter-wiper; but this is against practice, for such rollers are soon destroyed by the concussions of the machine. In case a roller is used, and a uniform motion is required, the centre of the roller is to be the true line, and the wiper is reduced for the radius of the roller, similar to that operation where a friction roller moves over an eccentric.

In constructing stamping-mills, it is advisable to make the wipers as short as possible; for this diminishes friction, and consequently secures durability to the machine. To arrive at this, the stamper or cam-shaft is to have as large a diameter as circumstances will admit of. It is also advisable to lay the lower side of the counter-wiper below the centre of the cam-shaft, as it tends to reduce friction.

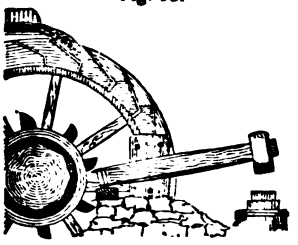
The time required for a stamper to fall from a certain height is an important item in constructing machines of this kind. A heavy stamp with a moderate lift will perform more strokes per minute than a light stamp and high lift; but they cause more friction, and consequently absorb more power, for the same labour performed. The limits of lifts are from six to twelve inches, and the number of strokes is from 120 to 80 respectively.

From the foregoing it may be easily perceived that the forms of eccentrics are evolvents, or parts of evolvents, in case they produce uniform motions. The hart-wheel, moving a point, is an evolvent drawn from the smallest circle, the height of which is in proportion to the angle of rotation.

TILT-HAMMERS.

In many instances we calculate on making more strokes with the stamper than could rationally be expected if the return motion was dependent upon the velocity of the free

Fig. 93.

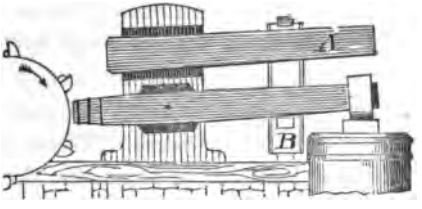


descent. This is the case in tilt-hammers, as represented in fig. 93. If the hammer had only six inches lift, we could not expect to make more than 100 or 150 strokes per minute. These hammers, however, are often required to make 200 strokes by 10 inches lift, 300 by 6 inches, and from 400 to 500 strokes by 2 or 3 inches lift. To increase the natural velocity, a piece of timber, covered by an iron or steel plate, is inserted under the tail-end of the hammer-helve, which timber acts as a spring, and, by its recoil, increases the velocity of the descent of the hammer-head. If the increase of the descending velocity is not sufficient to produce the number of strokes required, the cam-shaft is driven at such speed, that the tappets only touch the tail for a moment, throwing up the hammer-head with great velocity, and of course increasing the speed and the force of concussion by the increased recoil. The action of such hammers has therefore a most destructive effect upon the machine, and they ought to be strong beyond the usual calculations of strength.

The destructive effects of the common tilt-hammer upon the fulcrum, and consequently upon standards and foundations, has led to constructions which are intended to prevent, or at least modify, these effects. The object is imperfectly accomplished by fastening a spring-pole, A, fig. 94, in the standards; this spring-pole receives the strokes directly from the hammer-head, and, acting by recoil upon it, throws it down upon the anvil without affecting the fulcrum. This may be done in a more perfect manner by fastening the spring-pole to separate standards, which are

not connected with the hammer-frame; action upon that frame is thereby avoided. Even with this arrangement, the effects are still very destructive at heavy hammers,

Fig. 94.

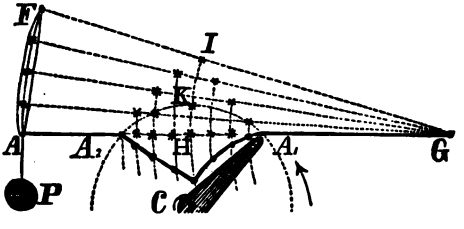


such as those of 200 pounds or more. Perhaps a better arrangement than either we have referred to, would be to lift the hammer at B, between the head and the fulcrum, and have the spring-pole entirely separated from the hammer-frame.

LIFTING A STAMPER OR LEVER BY A CRANK.

If a lever or stamper is to be lifted by a crank, the question is to give the sliding surface such a form, that the

Fig. 95.



weight bearing upon it is in all points the same. If, in fig. 95, C is the centre of a crank, which is to lift the

weight P, so that the resistance upon the crank in all positions is the same, while it moves through the arc $A_1 A_2$, we describe with the lever GA the arc AF, and draw the chord AF, dividing it into equal parts; these parts, drawn parallel to GA, form the divisions in the arc AF. We now draw the dotted lines from these divisions in the arc to G, the centre of the lever. Then divide half of the arc described by the crank into four equal parts, or as many as AF, and from these points of division draw parts of circles towards C, from G as their centre. Where these latter circles cut the lines representing the lever, there are the relative lengths of arcs, which, when measured from the lowest line GA, will give the length HI, which is drawn through the middle of the arc belonging to the crank. If the length IH is transferred from K towards C, the lowest point of the real form of the lever is obtained. In operating upon all the other points of the arc in a similar manner, we obtain the elements to the curvature of the lever, which are points in the arcs drawn from the centre of the lever G. The construction of the one-half of this lever—that is, the part nearest to G, or the ascending part—is a strongly-bent curve; the other, or the descending part, is nearly a straight line. If the curve is calculated for lifting only, the latter part of it is not needed. It does not make any difference whether the body to be lifted is in the form of a lever or a stamper; in the latter case, the lines GA to GF are of course parallel, instead of being radii to a circle.

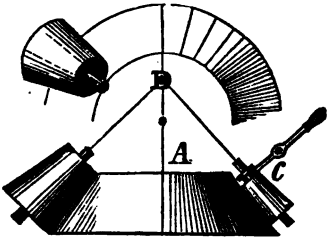
ROTARY MOTION.

The most perfect means at our disposal for converting one rotary motion into another, are cog-wheels and friction. This conversion is a subject of very general application,

and enters largely into mechanical constructions. We shall first consider that accomplished by friction.

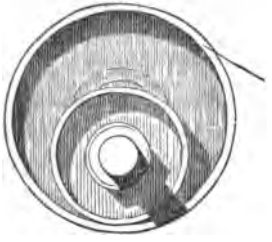
When two wheels or pulleys move upon one another, we may generally conclude that the number of their revolutions about their axis is as their diameters or periphery. The force by which two wheels are held together, determines their adherence; and as this adherence is caused by friction, we find the value of friction by referring to the tables. The force by which the two wheels are held together, expressed in weight, and multiplied by the coefficient of friction, is the amount of resistance which the driven pulley will offer to a disturbing force. In this calculation we have to consider the surfaces which are in actual contact, as we shall show hereafter. If the speed of the driving pulley is uniform, we may alter that speed, as well as its direction, by various means. If a cone, A, (fig. 96) is revolving around its axis, we may cause one or more cones to revolve upon it, with different speed to the first; the latter depends upon their various diameters. In all cases, however, the two sides of the cones moved, as well as that moving, must fall together into one point D, as well as their various axes. The driven cone may be movable upon its axis, as shown in CD, by which means the revolutions of the moved cone are changed. In all these cases, the planes of contact are small, and, if a considerable amount of force is to be transmitted by them, they are insufficient; still, the motion is so perfect in its nature, that more frequent use of this change of rotations ought to be made. If, instead

Fig. 96.



of running the two circumferences together outside of the respective wheels, we put one wheel inside of the other, as shown in fig. 97, the surface of contact and the amount of friction is increased. In this instance of rolling bodies, friction increases with the surfaces, which are here enlarged to a considerable extent, particularly if the wheels are nearly of the same diameter. If changes of speed are required, when this arrangement is made use of, cones instead of cylindrical pulleys are employed; they afford a far larger surface than the arrangement represented in fig. 96.

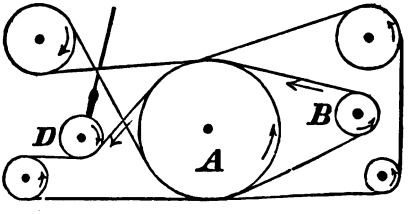
Fig. 97.



BELTING.

For the transmission of rotary motion, belts and strings are generally used; iron chains have also been used, but they are now almost universally abandoned for wire ropes. If an India-rubber, leather, or any other description of belt, passes around the pulley A, fig. 98, it adheres to it

Fig. 98.

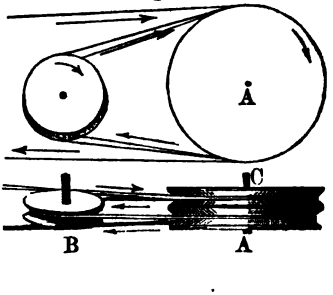


with a certain force, which may be called friction. But this is a compound force; and its elements, friction, rest, adhesion, and chemical affinity, are all to be considered. A

certain tension of the belts is always required to prevent their slipping; besides which, the angle of contact is an element of adhesion. The formula for the force F, which is to be transmitted by a belt of the tension t, is log. $F = \log. t + \cdot 434 \times C \times \frac{S}{R}$, in which C is the coefficient of friction, and log. the common logarithm; S is the arc of the pulley covered by the belt, and R the radius. The common coefficient of friction cannot be applied in this case; it is ·47 for greased leather upon wood, ·50 for dry leather upon wood, ·28 for dry leather upon cast-iron, ·38 for oiled leather upon cast-iron, and ·50 for new hempen rope upon wood. India-rubber belts may be classed with oiled leather. To increase the arc on the driving pulley, that which is driven may be made smaller, as shown in B, fig. 98; and to increase the arc on both, the belt is crossed, as in C. In many instances, the arc as well as the tension is increased by a tension pulley, D.

In cases where all these means are insufficient to produce the adhesion required, the belt is put around the pulley more than once, to afford it a longer time of contact. This is particularly resorted to where ropes are to pull a heavy load, such as wire ropes on an inclined plane. This arrangement is represented in fig. 99. If the pulley A is a grooved pulley, of which at least two are fastened to the same shaft, as shown in CA, the rope is directed upon one of these pulleys, and, passing around it, goes to B, which is a loose pulley revolving about an uncon-

Fig. 99.



nected shaft. The axis of B is inclined to the axis of A, so much so that the groove on one side of B corresponds with A, and on the other side with C. The rope, therefore, in passing around B, is led from A to C. The number of pulleys may be multiplied, if two are not sufficient, by providing, for each additional pulley at AC, one at B. This method of increasing friction is preferable to the tension roller, as here no increase of tension is required; and it has the additional advantage of the rope or belt being always bent in the same direction, making it more durable.

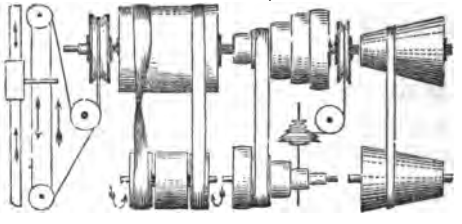
The mode of operation in determining the strength and size of a belt, is to find first of all, the amount of labour to be performed by it. This labour is its tension with velocity. If a belt passes over a pulley which makes one hundred revolutions per minute, and the pulley is three feet in diameter, its velocity at the periphery, and consequently that of the belt slung around it, is $100 \times 3 \times 3{\cdot}1415 = 942{\cdot}45$ feet per minute; if this belt is to transmit two horses' power, its tension on the pulling side is $\frac{2 \times 33{,}000}{942{\cdot}45} = 70$ pounds. In this case it is assumed that one side of the belt is slack; if this is not the case, which in the average of practical instances may be depended upon, the tension on the following side of the belt is subtracted from the above. We here see of how much more service the horizontal belt is than the vertical, for it increases the tension by its own weight, and also the arc of contact. In most of these cases we may neglect the width of the pulley in the calculation of friction; for the strength of the belt, if sufficient to resist the tension, makes the belt wide enough for adhesion. The width of the pulleys is, in all instances, at least as wide as the belt, and in most practical cases it is wider. In all cases it is advisable to make the belts

sufficiently wide; no other loss arises from too wide a belt than that of first cost, and the loss in rigidity. If a belt is too narrow, or the arc of contact too short, the tension must be increased, in order to afford sufficient adhesion to the pulleys. This tension bears upon both journals of the shafts, and increases the friction twice with the increase of tension. If a tension-roller is applied, the friction is increased still more, partly because the number of journals is increased, and partly on account of the rigidity of the belt, this being bent upon the tension-roller in an opposite direction to that of the pulleys.

At the present time the application of belting for the transmission of motion and power, is becoming more general than it used to be; and not unfrequently we see the power of a twenty-horse steam-engine transmitted by leathern belts, instead of cog-wheels, as was formerly done. There is no rational objection to this system of transmission, provided the belts are properly applied. General rules for the sizes and tensions of belts and pulleys cannot be given; it depends too much on the materials of which they are made; we will however furnish those principles which have a general bearing upon this question. Belts are usually constructed of leather—those made of India-rubber have not obtained that application which guarantees their superiority to the first material. The leather used ought to be cut in the direction of the length of the hide, that is, parallel with the spine; it must be well tanned, and oiled with whale-oil, or some other—not siccative oil. A superior material for oiling belts is a solution of India-rubber in common linseed oil, which may be rubbed into the belt in the course of its operation. This causes the belt to be very soft, makes it adhesive, stronger, and more durable than common leather. Short belts are very dis

advantageous, and so are vertical ones; they always require more tension than either long or horizontal belts. Those which are too narrow will stretch, in consequence of which, tension and adhesion are diminished. The adhesion of leather upon iron and smooth surfaces is greater than upon wooden and rough surfaces, for these reasons—pulleys ought to be made of iron, and perfectly round and smooth. Frequently we see the surface of the pulleys convex, in order to prevent the running off of the belt: this convexity must be very small, or it will diminish adhesion. The most perfect is the cylindrical form of pulleys, for flat belts. Round ropes, or strings, are conducted by grooved pulleys, in which the adhesion of the rope is increased by the wedge-form of the groove into which it is squeezed; the adhesion of these ropes to the pulleys increases, therefore, as the angle of the groove diminishes. Round grooves are disadvantageous, because they are destructive to the rope, caused by its sliding on the sides of the groove. The best form for the groove is a triangle, so that the rope touches but in two places tangental to its circumference.

Fig. 100.



By means of belts we may produce a great variety of motions from a given rotary motion. This may be either a uniform or an irregular motion; we may convert it into almost any kind we choose. In fig. 100 some of the most common motions of the belt are represented.

COG-WHEELS

Is another means of converting either the velocity or direction of a rotary motion into another rotary motion. The most common application of these wheels is to change the speed of one motion into another. The circumferences of the wheels are then inversely as the number of their revolutions. This law applies to the radius and diameter, or number of cogs, as well as to the circumference. If there are a number of wheels which transmit motion, then the number of cogs of the driving-wheels multiplied, divided by the number of cogs of the driven wheels multiplied, the quotient multiplied by the speed of the first mover, gives the speed of the last driven wheel. If the distance of two shafts is known, and the number of revolutions which each is to make, then the number of cogs in each wheel is inversely as the number of revolutions; and as the number of cogs is as the radius, diameter, or circumference, the number of revolutions are also inversely as the radius, diameter, or periphery. The circles thus arrived at are those of division, or pitch-circles; in these circles the division into cogs and spaces is performed. Before a cog-wheel is constructed we have to determine the thickness of the cog, which is found by referring to the power it is to transmit; from this we find the pitch, or the distance from the middle of one cog to the middle of the next, including cog and space. We have also to decide the width of the wheel or cogs, and the length of the cog in its radial direction.

DIMENSIONS OF COGS.

If we contemplate the labour a wheel is to perform, that is, the force it is to transmit, we obtain the pressure a cog is to sustain. Its force must be equal to the pressure upon

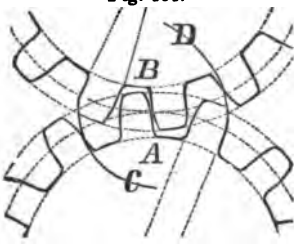
it, if it is to resist rupture; and it must be superior to the pressure, if any concussion (back-lash) happens to have influence upon the wheel. The influence of the latter force we have spoken of before; it is a very potent force, and ought to be reduced to the least amount by correct division, and as little play as possible. The first, however, has the most influence in cases of uniform velocities; but where the velocities are irregular, as is the case in most steam-engines which are driven by cranks, the space or play is of equal importance. If the force a cog is to transmit is known, which must be supposed, in all cases, we obtain its thickness by multiplying the square root of that force in weight by a coefficient belonging to the material of which the cog is made. If P is the power, and C the coefficient, the formula is $C \times \sqrt{P}$. The coefficient for cast-iron, is ·105; for brass, ·131; and for strong wood, ·145. We have now to convert P, in order to obtain a measure for the cog, from weight into measure, which, in inches, is divided by 4, when P is expressed in pounds. The formula is then $\frac{C \times \sqrt{P}}{4}$ in inches. The width of the wheel is generally five times the thickness of the tooth for small wheels; for large wheels, which are to transmit great power, and work with great velocity, it is often increased to eight times the radial thickness. The length of a cog is never to be more than 1·75 of its thickness, and in most cases is only 1·50 of it. The spaces are frequently 1·14 of the thickness of the cog, in rough-cast wheels; in cut or chipped wheels they should not be more than 1·06; this subject is, however, in a great measure decided by the sizes of the respective wheels. It is out of the question to furnish exact formulæ for the strength of cogs, because different materials, and also the different

qualities of the same material—such as cast-iron, of which cog-wheels are chiefly made—make deviations from the above rules necessary. As the thickness of a cog must be necessarily limited, in order to prevent concussions and vibrations, which absorb power, and are destructive to the machinery, it is advisable, in doubtful cases, to increase the width of the wheel, in order to obtain strength; it is better than to increase the thickness of the cogs. The form of small wheels is too weak if calculated according to the formulæ, which are correct for large wheels only. This circumstance does not arise from the insufficiency of the rules, but is caused by the qualities of cast-iron, which follows other laws than those developed by mathematics. In practice a great deal depends upon the quality of the iron used, and the machinery to be propelled. A cog-wheel which is to drive a train of rollers, or what requires still stronger wheels, a tilt-hammer, must be much stronger than one which drives a cotton-mill, if such wheels transmit the same amount of power. In all cases where sudden shocks, or concussions of any kind, are to be overcome, the best iron and abundant strength ought to be provided. The dimensions of the wheel depend more upon the quality of the metal, form of the pattern, and its destination, than on the actual resistance it is to overcome. An inquiry into these causes of modifications of form would lead us beyond our limits. The thickness of the wheel's periphery, the strength and number of arms, as well as the form of the nave, are more or less practical considerations, depending upon material, use, and form of the wheel; in all these instances superabundance of strength is necessary.

FORM OF COGS.

If the dimensions of two wheels are determined, as well as the size of the cogs and spaces, the wheel is drawn on a board, as is shown in fig. 101. The starting-point for the division of the wheels is where the two pitch-circles meet in A. It is advisable to determine the exact diameters of the wheels by calculation, if the difference between them is remarkable; for any division upon two circles of unequal size, by means of a divider, is incorrect, because the latter measures the chord instead of the arc. From the point A we construct the epicycloid C, by rolling the circle A upon B, as its base line. The construction of the epicycloid has been shown in Chapter II. That short piece of the epicycloid, from the pitch-line to the face of the cog, is the curvature for that part of the cog and the wheel B. This curvature obtained for one side of the cog, serves for both sides of it, and also for all the cogs in the wheel. The lower part of the cog, or that inside the pitch-line, is immaterial to the working of the wheel; this may be a straight line, as shown by the dotted lines which are in the direction of the diameters, or may be a curved line, as is seen in the wheel A. This line must be so formed as not to touch the upper or curved part of the cog. The root of the tooth, or that part of it which is connected with the rim of the wheel, is the weakest part in the cog, and may be strengthened by filling the angles at the corners. The curvature for the cogs in the wheel A is found in a similar manner to that for B. The

Fig. 101.



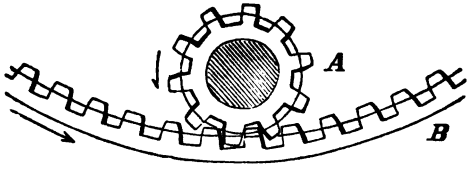
pitch-circle A serves now as a base-line, and the circle B is rolled upon it, to obtain the epicycloid D. This line forms the curvature for the cogs of A, and serves for all the cogs in A—also for both sides of the cogs. In most practical cases the curvature of the cogs is described as a part of a circle, drawn from the centre of the next cog, or from a point more or less above or below that centre, or the radius greater or less in length than the pitch of the wheel. Such circles are never correct curves, and no rule can be established by which their size and centre meets the form of the epicycloid. This proceeding is particularly wrong where there is a great difference in the lengths of the diameters of the wheels. For large drivers, and small driven wheels, it is essentially necessary to construct the epicycloid, if good work is expected. When the driver is small in proportion to the driven wheel, it is advisable to make the spaces smaller than usual. The spaces may be equal to the cogs, and, in very small wheels, even smaller; because in these instances there is hardly more than one cog at once in contact, in which case large spaces cause back-lash.

If wheels are very large, sliding friction is very small; it is all expressed in rolling friction. Wheels of equal diameter cause less friction than those of different diameter. The friction increases in a greater ratio than the difference of the diameters. As a general rule, we may assert that friction increases inversely as the number of cogs in the smaller wheel. As the time of contact, or the length of the curve, is an element of friction, it is advisable to make that curve as short as possible. The amount of friction in any wheel is obtained by multiplying the weight which acts upon the cogs by the length of the curve for one cog, and this by the number of cogs which come in contact in one

minute, in fact; the whole, divided by the measure of one horse-power, gives the amount of friction, expressed in horse-powers.

The friction of cogs increases with the difference in the diameters of the wheels; it increases also inversely as the diameters. Friction is therefore greatly diminished by moving the convex part of one wheel in the concave part of the other, as is shown in fig. 102. The curvature of

Fig. 102.

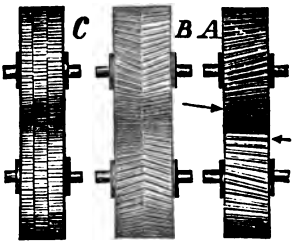


the cogs is here obtained in the same manner as in fig. 101. By rolling A upon B as the base line, we obtain the curvature for the cogs in B; and by rolling B around A, we obtain those for A, which is a straight line in case A is half as large as B. The form of these wheels, when properly constructed, affords great advantages over other forms, in being more durable, and causing less friction; but they require strong arms and naves to resist the side pressure of the cogs upon the arms and shaft.

SLANTED COGS.

Face wheels are liable to cause vibrations in the shafts and machinery connected with it, because of the space or play between the cogs. This evil has been in a great measure overcome in small machinery, such as turning lathes and spinning machines, by slanting the cogs to the axis of

Fig. 103.

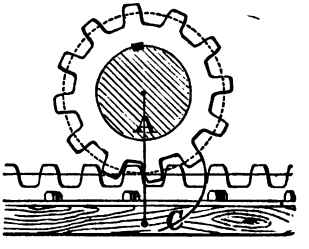


the wheel, as represented in fig. 103, A. These means are sufficient to overcome one difficulty; but another presents itself, namely, a side motion in the direction of the axis, in consequence of the inclined planes which the cogs form with the axis, or the plane of the wheel; that motion is in the direction of the arrows. To obviate this difficulty, wheels have been made with angular cogs, as shown in B. This kind of wheel shows difficulties in execution which can hardly be overcome. A better plan than either of the above, is that represented in C; this is also applicable to large wheels. The cogs form here a kind of steps; or, what is the same, two or more wheels of the same pitch are cast or screwed together. These wheels have the disadvantage of not admitting of any regulation of the teeth; they must be either cast perfectly true, or screwed together; in the latter case, the teeth may be cut, if the wheel is small.

RACK AND PINION.

We may here allude to the construction of rack and pinion. The dimensions of the cogs are found by applying the same rules as those for cog-wheels. The curve for the working part of the cogs in the wheel is, in this case, the evolvent to the pitch-line, drawn from the point of contact in the line A, fig. 104, to that point where the cog of

Fig. 104.

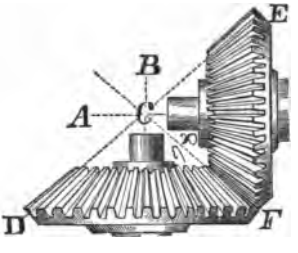


the pinion leaves the rack, which is the line C. The string for drawing this evolvent is of course longer in large than in small wheels. The curvature for the cogs in the rack is the cycloid. That part of the cogs extending from the pitch-line to the root of the cog, may be a straight or curved line, provided it does not interfere with the curve of the teeth. In cases where a uniform motion of the rack is required, as those of a common form are not perfectly free from vibrations, we may adopt the form of cogs represented in fig. 103.

BEVEL WHEELS.

If the axes of two wheels are not parallel, the principles by which the forms of the cogs are determined are not altered; their practical form, however, differs from the square or face wheels already described. If the lines CA and BC, fig. 105, represent the prolonged axes, which are to revolve with different or similar velocities, the position and sizes of the wheels for driving these axes are determined by the distance of the wheels from the point C. The diameters of the wheels are as the angles α and β, and inversely as the number of revolutions. These angles are therefore to be determined before the wheels can be drawn. By measuring the distances from C to the line E, or from C to F, the sizes of the wheels are determined. These lines, EF and DF, are the diameters for the pitch-lines; from them, the form of the cog is described on the bevelled face of the wheel. If the form of the cog is described on the largest circle of the wheel, all

Fig. 105.



the lines from this face run to the point C, so that, when the wheel revolves around its axis, all the lines from the cogs concentrate in the point C, and form a perfect cone. Curvature, thickness, length and spaces, are here calculated as on face wheels; the thickness is measured in the middle of the width of the wheel.

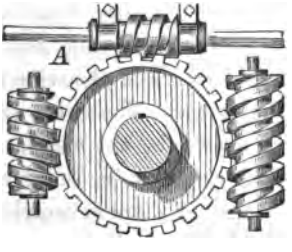
FORM OF COGS FOR MORE THAN TWO WHEELS.

If a system of wheels is to work in one wheel, or if a series of large and small wheels are to be driven by a common master-wheel, the curvature of the cogs should not be an epicycloid. It is advisable here to adopt the evolvent, and make the string as long as the pitch of the wheel, describing, of course, for each wheel, its particular curve. Even this curve is not quite correct; but it approaches correctness more nearly than the epicycloid. All other forms of the cogs are similar to those already described.

WORM-SCREW.

To this class of motion belongs also the worm-screw. If a single screw, A, fig. 106, works in a toothed wheel, each revolution of the screw will turn the wheel one cog; if the screw is formed of more than one thread, a corresponding number of teeth will be moved by each revolution. With the increase of the number of threads, the side motion of the wheel and screw is accelerated; and when the threads and number of teeth are equal, an angle of 45° is required for teeth and thread, provided their diameters also are equal. This motion

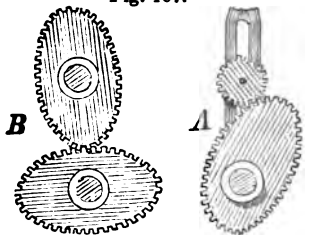
Fig. 106.



causes a great deal of friction, and it is only resorted to where no other means can be employed to produce the required motion. In small machinery, the worm is frequently made use of to produce a uniform, uninterrupted motion; the screw in such cases is made of hardened steel, and the teeth of the wheel are cut by the screw which is to work in the wheel. If the form of the teeth in the wheel is not curved, and its face is concave so as to fit the thread in all points, the screw will touch the teeth but in one point, and cause them to be liable to breakage.

ECCENTRIC COG-WHEELS.

Fig. 107.

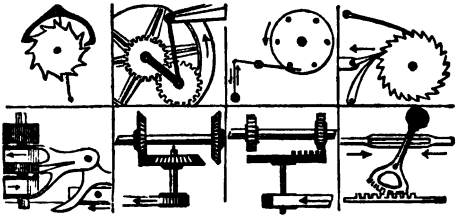


When two wheels, one of which is an eccentric, as shown in A, fig. 107, work together for the purpose of producing irregular motion in the axis A, the line of pitch is determined and drawn upon a board, so cut as to be the perfect form of the line of division. A drawing around this is made upon another board, and, by means of compasses, a series of circles is drawn in this line, equal in diameter to the length of the cogs. By connecting these circles inside and outside, a parallel space is described, which represents the length of the teeth. The curve of the teeth for small wheels may be drawn by the compass from the points of division; but, in larger wheels, the curvature is to be the evolvent. If both wheels are eccentric, as shown in B, the operation for determining the form of the teeth is the same; but it is necessary to the correct working of the wheels that the curvature of the cogs should be the evolvent. The base part of the teeth are lines concentrating in the centre of the wheel.

ROTARY INTO OSCILLATING MOTION.

In fig. 108, a variety of these motions are represented, which require no explanation. Any rotary motion may be converted into a regular or irregular motion, and then into linear regular or irregular motion.

Fig. 108.



CHAPTER VIII.

THE MEASURE OF MOVING POWER.

MUSCULAR POWER.

In the motion of men and animals, a certain power is consumed, which may be measured. It is not our province to inquire into the causes of motion, or the sources of force, in this instance; still, it cannot be considered an inappropriate remark, that the amount of power produced by any individual is dependent upon the amount of food consumed, and the manner in which it is digested. In order to produce power, it is necessary that food should be consumed and digested by healthy individuals. Young persons consume a large amount of food, which goes to increase their body; but they cannot perform much labour. Aged persons use a great deal of food to keep up the animal heat required to sustain life. It is the middle-aged who are able to do the greatest amount of work in the shortest time. These rules allude to all classes of men and animals. The engineer has no connection with the development of this kind of power; but it is his province to select the individuals most qualified to do the largest amount of work. The work performed by animals depends upon their species, age, temper, and management; the latter is the engineer's legitimate field, and it is his duty to know the best manner of putting his force at work. The working capabilities of individuals depend upon their

own exertions; that is, the time they work, the speed with which they operate, and the amount of work done. These elements form a mean effort, or a maximum of labour performed. An animal may be over-exerted for one or more days, which would show a large mean; but the following days would furnish a less favourable result, which, when compared with the first, would show the average labour performed during a certain time. Any individual may perform, for one day or longer, more labour than actually belongs to his quality; but it is the average work which can be performed without fatigue, which constitutes the measure of labour. In measuring muscular labour, we generally take a day's labour, or a longer period, and reduce it to the labour of one minute, or the standard usually agreed upon.

A man may walk forty miles as a day's work—this does not constitute labour; but if he carries ten thousand bricks to a certain elevation, he performs labour. The man who walks on a level road, merely shifts his body, without useful effect; but if he walks up stairs, he lifts his body, and performs labour. The engineer does not recognize any other exertion as labour, but that which is actually moved against certain active measurable forces. If a vessel is shifted on the surface of water, it may seem a parallel case to that of a man walking on a level road; but the vessel encounters in its motion the cohesion and impact of the water, and has to overcome a large amount of friction. Such resistances form the measure of labour performed in these and similar cases.

A man walking up stairs may carry his body in one minute 50 feet high; if his weight is 150 pounds, he lifts $150 \times 50 = 7500$ pounds one foot high every minute. This, however, cannot be considered work performed; for the

man is to go down stairs again. If, instead of letting him walk down stairs, we lower him in a machine, he may lift an equal weight of matter to himself, say brick or mortar, to the height from which he descends. If we assume that his descent requires as much time as his ascent, the above number is to be divided by two; the labour performed by the man is now $\frac{7500}{2} = 3750$ pounds lifted one foot high per minute. This we call nominal labour; it cannot be actual labour, for there are no impediments to his descent, such as friction, rigidity of ropes, resistance of air, and other considerations, of which we shall speak in our next chapter.

The speed with which a horse may walk and pull conveniently, is three feet per second; at this speed, a strong horse may pull a weight of 100 pounds over a pulley, the weight ascending vertically with the speed of the horse. If we multiply the speed of the horse by the pounds lifted and the time in which it is performed, we obtain the labour accomplished by the horse, which is here $3 \times 100 \times 60 =$ 18,000 pounds, lifted a foot high in one minute. By similar experiments, James Watt obtained 22,000 pounds, and also 30,000 pounds; and in order to form a unit of power which might most successfully represent that of a strong horse, he assumed that a strong horse might lift 33,000 pounds one foot high every minute. This measure is now so generally adopted, that we may lay it down as the unit of labour by general agreement.

DYNAMOMETER.

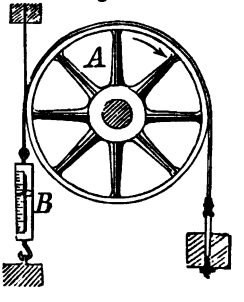
A common spring balance, or any other balance, may serve as a machine for measuring power; we can by these means measure a force either in motion or at rest. If we

pull a common spring-balance by a certain force, we at once obtain the weight in pounds by which a certain force is arrested, or kept in suspension. These means serve for measuring the muscular force of men and animals, and also the power of concussion; but they are not adapted to measuring the labour performed by a machine in motion. The most simple form for measuring concussion is the pendulum, by observing its oscillations; but the operation includes calculations which are not suitable for our purposes. The instrument generally in use is the spring dynamometer, which is constructed on the principles of a spring-balance, receiving the stroke, and, by having a movable pointer, which stops at the extremity of the motion, and indicates at once how many pounds the body in motion was able to move to a certain distance.

FRICTION BRAKE.

Machines in motion cannot be measured by the above means, as the labour performed is composed of velocity and pressure; the first is to be measured, but the latter must not be interfered with in the operation. The most simple means for accomplishing this purpose is to convert all the labour performed by a machine into friction, and then measure that friction; this is accomplished by the friction brake. If A, fig. 109, represents the revolving main shaft of a machine, say a horse-power, water-wheel or steam-engine, which shaft is turned perfectly round and smooth, for which an iron shaft or pulley is best qualified; and if we lay around this pulley

Fig. 109.

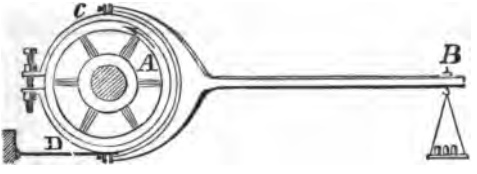


or shaft an iron hoop, fastened at one end to a fixed spring-balance B, and provide the other end with a screw to tie the hoop close to the pulley, so as to run the machine with its usual speed; all the power of the machine is absorbed by the friction between the pulley and hoop. If the machine so arrested is a mover, all the machines driven by it are thrown out of gear, so as to check the machine by the friction produced by the hoop on the pulley. The hoop will now pull the balance and show a certain weight at it, which weight is the resistance to the motion of the machine. If we now multiply this weight by the velocity of the circumference of the pulley, we have the labour performed by the machine at that particular point. Suppose the balance shows 50 pounds tension in the hoop, the pulley makes 100 revolutions per minute, and is 3 feet in diameter. We have here 50 pounds moved through a distance of $3 \times 3{\cdot}1415 \times 100 = 942{\cdot}45$ feet, or $942{\cdot}45 \times 50 = 47{,}122$ pounds lifted one foot high in one minute, or $\frac{47{,}122}{33{,}000} = 1{\cdot}4$ horse-power. This brake, however, is not perfect; for it increases the amount of friction in the journals of the shaft, and that friction is not shown by the balance. The hoop may be laid entirely around the shaft, as indicated by the dotted lines; but this arrangement does not entirely obviate the evil. Instead of the spring-balance, a scale may be used, and weights applied directly.

A more perfect friction brake is that represented in fig. 110. Here, if A is the shaft, or a pulley fastened to it, the lever B joins it in the points of its fork CD. An iron ring is fastened near this fork, which fits closely to the round shaft, and which may be tightened by a tie-screw. At D, one end of the brake is fastened to a fixed object. The weight of the lever, including the platform for the

weights, must be ascertained, for the point B, from the centre of A, around which it is movable. The iron belt is tied so closely to the shaft, as to permit the ungeared ma-

Fig. 110.



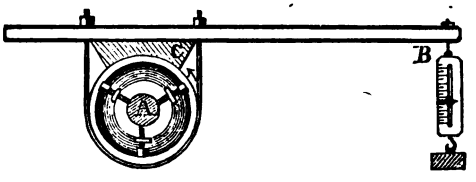
chine to make its usual number of revolutions. On the platform at B is now put as much weight as is requisite to pull it downward, so as to slacken the fastening at D; and the machine is urged so as to balance its power completely by the weights.

If the pulley is here two feet in diameter, and the lever five feet long from the centre of the shaft, or from A to the point of suspension B; and if the weight of the lever is 25 pounds in B, and there are 75 pounds weight on the platform, the shaft making 50 revolutions per minute, the power of the machine is $\frac{50\times(75+25)\times4\times2\times3\cdot1415}{33{,}000} =$ 3·8 horses. This brake obviates the imperfections of the other to a considerable extent, but is still not generally applicable.

There is yet another instrument, superior to either of the others, which is represented in fig. 111. To the shaft A, a pulley is fastened by pinch-screws, and properly adjusted, so as to run concentrically, and without waving. Around the pulley fits an iron hoop, whose ends pass

through the lever B, and may be tightened by screws, so as to produce the required friction; a metal block, C, acting opposite to the hoop. At the end B a spring-balance

Fig. 111.



is adjusted, one end of which is fastened to a fixed object. The operation is here very simple; the length of the lever is measured in the direction of the dotted line, and the weight of the lever bearing on the point B must be brought into the calculation.

This brake has the advantage of being applied to either vertical or horizontal shafts with equal facility. The whole apparatus is movable, and may be fitted in a short time to any shaft.

CHAPTER IX.

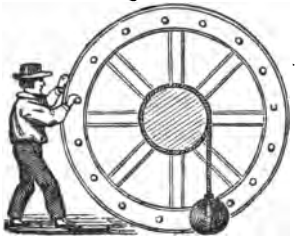
EFFECT, OR LABOUR PERFORMED BY MACHINES.

HUMAN LABOUR.

If a man walks up stairs he does not make use of any machine, at least not in the sense in which we speak of machines. But in descending, he uses a machine, if he endeavours to perform any labour at all. In the following pages we shall inquire into the amount of labour performed by machines which are in use for the transmission of power. The manner in which a man may perform the most labour is by walking up stairs, and descending in a rope-machine, lifting over a pulley a quantity of material, more or less equal to his own weight. If the machine is a simple pulley, over which a rope is slung, and man and burden rest upon platforms at the end of the rope, the loss in power will depend chiefly on the form of the machine and platforms. A large pulley will cause less friction than a small one, or even two pulleys, when the distance is great between the ascending and descending rope. The rigidity of the rope will also cause less resistance in large than in small pulleys. An important element in the loss of labour is the motion and resistance of air. The latter is greatly diminished if the form of the platform is half a sphere, as we have seen in a previous chapter. The loss of labour by speed is an element well known. If the space of free descent, in two seconds, is 60 feet, and a man descending on a machine uses four seconds, he will work with but half

his weight, for one-half is lost in velocity. If he uses eight seconds for descent, he will lose but 25 per cent. of his weight. The slower therefore the motion, the more labour is performed; which advantage is increased, in considering the decrease of resistance in the air and the rope, with the diminishing of speed. If a man can walk 60 feet high in one minute, and it takes four minutes to come down again, his labour is equal to $\frac{60}{4+1} = 12$ feet high in one minute; and if the machine loses an additional 25 per cent., the labour of a man is reduced to nine feet high, which is equal to nine times his own weight one foot high; and if the man's weight is 150 pounds, his effect is $150 \times 9 = 1350$ pounds one foot high per minute. A man who pulls a weight over a pulley, by a rope, may lift 40 pounds perpendicular with a speed of six inches per second; this makes $\frac{6}{12} \times 60 \times 40 = 1200$ pounds one foot high every minute. If a man carries a weight up stairs he will produce but 800 labour; and in a wheelbarrow, up an inclined plane, only 600. A man, by means of a shovel, may lift 500 pounds of sand or loose ground, one foot high per minute, provided the height to which it is to be raised is not more than four or five feet. A man will perform most labour at the wheel, (fig. 112,) which amounts to 4000 pounds. Turning a shaft in a crank, as is the case in a common whin, or a windlass, a man may lift 2400 pounds; and by pulling a rope over a pulley he is able to lift 3000 pounds. In a fire-engine, where a man works up

Fig. 112.



and down, he may do the work of 2300 pounds for a short time.

A man in moving on a horizontal road may make 110 steps, at two feet six inches, in a minute, for ten hours a day, and if he weighs 150 pounds, he moves 150 pounds, $110 \times 2\frac{1}{2} = 275$ feet, or 41,250 pounds one foot every minute. In a light two-wheeled cart, a man may push 20,000 pounds one foot, and return empty; it appears from this that the human body is the better or more perfect of the two machines. For, if we consider in the case of the cart, that the man is to follow the cart, and return with it, which taken all together does not reach the first labour, or that of the man without the cart, it follows that there is less friction in the human body than in the human body appended to a machine. If we compare the weight carried on the back of a man to that carried in a wheelbarrow, and compare labour, it appears that a man can do but half as much on his back as by means of an imperfect wheelbarrow; this shows how much friction is increased by pressure upon the soft joints, compared to that of the harder metal and wood. The wheelbarrow furnishes but half the labour of a two-wheeled cart; still it would be bad policy to use carts in canalling, for the lifting of ground to a height of three or four feet, by the shovel, is disadvantageous, because the shovel is one of the most imperfect machines. If a man can push 40,000 pounds per minute, in a cart, and can lift only 1200 pounds vertically, it appears that the coefficient of friction is $\frac{40 \times 000}{1200} = 33{\cdot}3 : 100 = 3$. This, in the wheelbarrow, is from six to twelve, and in the loaded human body, it supersedes both, and progresses rapidly.

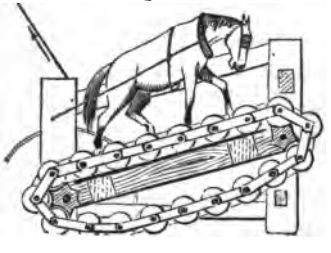
In lifting water by means of buckets, a man may raise

600 pounds one foot per minute, provided the height is not more than two feet. He may do the same by means of a scoop; if it is suspended by a chain, a weight of 1800 pounds may be raised. By means of a hand-whin a man may do the same amount of work; in pulling a rope over a pulley, however, he may do one-fifth more.

HORSE POWER.

A horse pulling a weight by a rope may be expected to perform a great deal of labour; he can pull a weight of 150 pounds with three feet speed, and do that work for ten hours a day; this makes $150 \times 3 \times 60 = 27{,}000$ pounds lifted one foot high per minute. The imperfections of a common horse-whin, where the horse pulls in shafts, and walks in a circle, are so great, that he cannot lift more than 14,000 pounds. A horse-whin, commonly called horse-power, where the horse works on an inclined plane, as shown in fig. 113, and where he works with his weight, and also pulls, does not yield so much labour as the common whin. If a horse moves with a speed of from six to seven feet, or is trotting, he cannot perform more than three-fourths of the labour which he does at a speed of three feet, and that but for a short time. If the speed is increased still more, the horse yields rapidly less, and, at its greatest speed, cannot pull at all. The most advantageous application of horse-power is in railroad cars; here a horse will do as much work as in lifting a weight over a pulley: the next to this is in towing canal-boats, and in a common horse-

Fig. 113.



whin of a large diameter. Another method of employing horses, or other quadrupeds, for procuring their labour, is the horizontal rotary platform, such as we frequently find applied to ferry-boats, to drive the paddle-wheels.

Fig. 114.

Fig. 114 shows an arrangement of this kind; four horses are walking on a horizontal rotary platform, two on each side of the boat, which drives the paddle-wheels by means of bevel-gearing. These horses work to great disadvantage, because it is performed in a small circle; still their labour is cheap compared with steam, in cases where but a limited business is done. Stationary platforms of this kind may be made larger than those in boats; they are also laid at an inclination, in order to apply the weight of the animals in the mean time. All these machines are imperfect, because the animal receives a twisting motion in his legs, which soon tires him, and reduces his capability of pulling.

If harnessed to a cart, or other vehicle, a horse can pull 1400 pounds, on a level road, for ten hours a day, with a speed of 3·5 feet per second; this gives, for every minute, $1400 \times 60 \times 3{\cdot}5 = 286{,}000$ pounds or feet, or nearly eleven times as much as a horse can lift perpendicular. This established the unity for other means of transport by the horse. In trotting, the horse cannot pull more than half that load, and that but for half the time, which re-

duces his labour to one-fourth of the above. If the horse is to return with the empty cart, after having unloaded, and the distance is as great one way as the other, he will not perform much more than half the labour assigned to him above. A horse may carry 200 pounds on his back, and walk ten hours a day, which brings his labour to $3{\cdot}5 \times 60 \times 200 = 42{,}000$ pounds or feet. The greatest labour is performed by the horse in moving his own body: he may go with a speed of ten feet, for ten hours a day, and if he weighs 600 pounds, he yields $10 \times 60 \times 600 = 360{,}000$ labour. If we take the last result but one, the horse performs $3{\cdot}5 \times 60 \times 600 + 42{,}000 = 168{,}000$ pounds or feet. This shows the superiority of the natural to the artificial machine, or the rapid increase of friction in the joints and muscles of the animal by increased weight.

POWER OF AN OX.

The labour performed by an ox is not great, because of his limited speed. An ox may walk for eight hours a day with a speed of 1·5 feet, and pull 130 pounds vertically; this brings his labour to $1{\cdot}5 \times 60 \times 130 = 11{,}700$ pounds or feet, not much more than one-third of that of a horse. In putting an ox to other machines, such as whins or carts, his labour assumes a more favourable aspect; still it hardly ever reaches half that of the horse.

POWER OF A MULE.

A mule can pull 70 pounds, with a speed of three feet, for ten hours a day, if put to a whin; this makes his labour $3 \times 60 \times 70 = 12{,}600$ pounds or feet, a little more than the ox. This result is increased by his pulling a cart or wagon, but never reaches the labour of a horse.

All the foregoing calculations depend, in a great mea-

sure, on the capacity of the animals. There may be some which will do more work than we have calculated, there are also some which do less; the average of all labour performed, under the various circumstances, is however within the limits of our figures.

THE SOURCE OF POWER IN ANIMALS,

As remarked before, is the food consumed. The conditions under which this act is performed, that is, the health and age of the animal, modify the amount of surplus power which the animal may expend in labour. A young animal consumes much food in order to increase its body; and an aged animal consumes food to keep up the vital heat necessary for its existence. Diseased animals, whose digestion is disordered, and whose vital energy is expended in the attempt to throw off that disease, cannot perform much labour. A horse consumes on an average eleven pounds of carbon and one pound of hydrogen in twenty-four hours; that is, he consumes as much food, such as oats, corn or hay, as will represent the above figures. The nitrogen taken in the food cannot be brought into the calculation, because it is expended in forming new parts of the body; besides, it does not combine with oxygen, and forms, consequently, no element of power. The above quantity of carbon and hydrogen is contained in the food, in chemical combination with each other, or with the addition of oxygen and nitrogen. These ten pounds of carbon and one of oxygen may be considered as equal to eleven pounds of bituminous coal, which would serve a common steam-engine for one hour to produce the labour of one horse. A good condensing engine might be supplied by that quantity for two hours, and a Cornish engine for seven hours. The horse may work ten hours a day

with the above amount of food; but his labour is scarcely equal to one-half of a horse-power in the steam-engine. The Cornish steam-engine apparently uses fuel to greater advantage than the animal. If, however, the amount of heat expended in increasing the body, or assisting in the metamorphosis of tissue, is taken into account in the animal, there is no doubt that we should find an economical application of the heat generated by the food.

WIND.

The next source of useful power which claims our attention is the wind; it may be considered the most extensive source, after muscular power. Winds are those currents of air which are caused by local expansions or contractions. The recipients of this force are generally windmills; an awkward, clumsy contrivance, but which can be made very useful where the currents of air are less changeable than is usually the case. Windmills are not adapted to this country, because, owing to the high price of human labour, the attendance they require is expensive; and further, because fuel is comparatively low, so that the labour of steam-engines becomes cheaper than that of wind. In Europe, however, windmills are much used; they are generally wooden or stone towers, from 40 to 80 feet high, the wings being vertical, and the axis from 5° to 15° inclined to the horizon. Windmills with horizontal wings have been found of too little effect to be of any practical use. The number of wings is generally four; still, there is no objection to using five or six, or even more, if we choose. We may make a round wheel of it, like a smoke-jack, as has been done ir Washington city.

The wings of a windmill are generally a strong framework of wood, which is covered by a movable sail-cloth.

The sails are also made concave, to expose hollow surfaces to the wind; and the wings are frequently found to be twisted in such a manner as to offer a strongly inclined plane to the action of the wind at their extremities, but less so in the centre. Windmills, on the whole, are unsatisfactory machines; a moderate breeze will not work them, and a wind of a velocity equal to that of a locomotive, or 35 feet per second, is too much for the sails, and they must be very closely reefed to resist it. A stronger wind than this makes it dangerous to work a mill; and in stormy weather it not unfrequently happens that the bare poles, even when at rest, are broken off by the force of the wind.

WATER-WHEELS.

Water is one of the most useful powers at our disposal for the driving of machinery; it furnishes a more regular supply than the wind, and, even in its excesses, is perhaps not so dangerous. In a previous chapter, we have been particular in reference to water-wheels, and there is but little for us to allude to here, except a few practical rules, and their application.

WIERS.

The application of water to a wheel makes it, in most cases, necessary to erect wiers or dams to create a head. Overfall wiers are the most common form of dams across a river, to swell the water, and back it sufficiently to produce the desired head. Small creeks and rivulets are frequently backed by a dam and sluice-wier, which retains all the water, the gate being only drawn so far as is necessary to let out sufficient water to prevent the overflowing of the wier. The construction of a wier is frequently found to be expensive at first, and still more so from the injuries which

it may receive, or which it may cause to other property. The cost, if a wier is constructed durably and well, will be found to be less than if it is put up cheaply and imperfectly; for repairs, delays, and damages, will bear more heavily upon a manufacturer than the interest on a rather larger original investment.

In erecting a wier, the first consideration of importance is its position in relation to surrounding property. A wier is to be located so as to cause as little injury as possible to the banks of the river. The greatest danger is always found to be below the dam; the water, in rushing over the wier, may undermine the banks, widen the channel, and cause injury to property, finally endangering even the structure itself. To prevent damages and injuries, wiers are built of various forms. Sometimes they are built directly across the river, in the shortest direction, and at the narrowest part, if the bed of the stream is rocky, and the surrounding property in no way endangered. If one bank of the river is rocky, and the other alluvial ground, as river bottom-lands generally are, it is advisable to build the dam obliquely across the river, making it higher at the rocky bank, and directing the current of the fall against

Fig. 115.

the rocks, as shown in fig. 115, in such a manner as to prevent a reaction on the opposite shore. In other cases, a wier is built in two parts, both inclined towards the

shores; the angle formed by these two parts is directed up stream; the back-water is thus thrown between the two parts of the wier, which breaks its force, and concentrates the agitated element between them. Wiers may also form a part of a polygon, a segment of a circle, a portion of an ellipsis, or any other curved line. The object of these various forms is to secure durability, and give protection to property.

The material of which wiers are built has no influence on the object to be attained, which is simply to back the current of the river so far as to obtain the height of head-water contemplated; but the kind of material, and its application, has a decided influence upon the durability of the structure. If it is the object, in erecting a temporary dam, to concentrate the water or raise its level but a few inches or feet, a wier may be formed of loose stones, such as large pebbles or refuse quarry-stones; or it may be made of stones and brushes, the latter being held down by the first. Such dams are of course not durable; the first flood generally carries them off. Cheap wiers may be erected simply of poles and planks; the latter being protected by stones below and gravel above, while the poles are driven in firmly by means of heavy sledges. A very durable dam may be formed by driving a line of vertical timbers, shod with iron, into the bottom of the river; the poles project as high as the weir is to be, and their tops serve to fasten the saddle-beam; the face of these posts is to be covered by a water-tight planking. A second row of posts is then driven some distance below the first, as high as low water-mark; these are planked on the upper side, and the space between these two rows of posts is filled with stones, as shown in fig. 116. The form of the slope, or shute, is of great consequence in the durability of the

wier, as, if it is of such a form as to admit of underwashing the lower row of posts, as shown in fig. 117, there is danger of the whole dam being carried away by a strong flood.

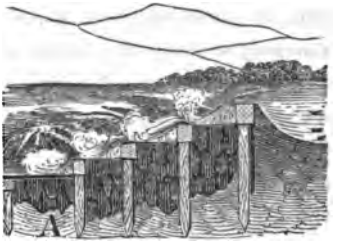
Fig. 116.

The protection of the space A is the most important object in constructing a wier; if a cavity is worked out by the water in that place, it is an evidence that there is something wrong in the form of the dam. In conducting water over a wier, the object is to break the force of the water in leading it down the shute. A very effective form for accomplishing this is that shown in fig. 116, where the water is thrown up by the curved stone, or plank-slope; but if the form is that represented in fig. 117, no material will prevent the washing out in the pool A. If stones cannot be used in erecting a dam, and the whole is to be constructed of wood, it is advisable to drive a series of rows of posts, and, by connecting these, form a series of steps, over which the water falls, and its force may be broken, as is represented in fig. 118, and protecting the space A by a well-extended apron. The spaces between the timbers are filled with heavy gravel. Smooth shutes and aprons are in all instances disadvantageous; the water in passing over it retains too much force, which is expended chiefly in

Fig. 117.

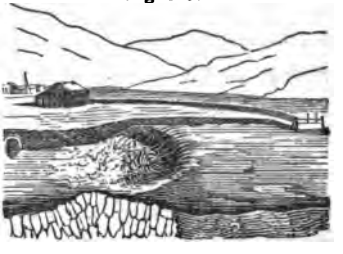
the destruction of the dam; the velocity of the current ought therefore to be broken before the water arrives at the lowest part of the apron.

Fig. 118.



Stone wiers, though very durable when well constructed, are, on account of their expense, not advantageous except where the bed of the river is rocky, and impervious to piles. In such cases, stone wiers are erected in a curved line across the river, so as to offer an arch to the current, and throw the back-water into the middle of the stream, as shown in fig. 119. In all these cases, straight wiers in the shortest direction ought to be avoided, as also straight aprons. There should always be a water-tight partition at the upper part of the wier, to prevent the rushing of a current through the timbers or stones, as such an under-current is inevitably very destructive. If such a partition cannot be formed by means of planks, it ought to be formed by heavy gravel above the dam.

Fig. 119.



The material of which dams are constructed is of great influence on their durability. Timbers ought to be selected of wood which will last under and above water, such as locust, white-oak, or red pine. To the quality of the stones, also, not enough attention is generally paid. All kinds of stone resist the influence of the atmosphere sufficiently well, so that they require but little attention on

that score; but the form of the stones is an object of the utmost consequence to the durability of the structure. If not well jointed, the stones should be as heavy as possible; and they should offer but little surface to the water, in order the better to resist the influence of the current. The specific gravity of the stones is another item, not always properly attended to; the heaviest kind of stone is the best in all instances. If stones are submerged, their specific gravity is diminished 1. If we submerge limestone of a specific gravity of 2, it is not heavier below water than is oak timber in the air; and a gentle current will carry it off. Granite of a specific gravity of 3·5 is still 2·5 below water, and a strong current is required to move it. Compact basalt of 4·5 is still heavier than granite, and of course not so liable to be washed away. In all instances, the heaviest stones should be selected, either for filling or for paving a dam. Stones of a volcanic origin are for these reasons preferable to stratified rocks; compact lava, trap, granite and basalt, are the best; limestone, shales and slates, and the sandstones of the coal formation, are inferior materials. For gravelling, the refuse or small stones of vitrified rocks are good; but the best material for this purpose are the slags from smelting furnaces, such as cinders from puddling furnaces, blast furnaces, and in fact all slags from smelt-works, whether iron, copper, or lead.

THE INLET.

The water from the pool above the dam is to be tapped so far above the comb as to be within the highest level, partly on account of safety, but chiefly to obtain all the head which can possibly be secured; the water is always lower at the comb of the dam, and a short distance above

it, than it is where the level is perfectly horizontal. The inlet is to be guarded by a flood-gate of substantial timber, and sufficiently high to reach above the highest floods of the river; it not only serves to regulate the supply of water to the race, but guards against the injurious effects of freshets.

WATER RACES, OR CANALS,

Are cheapest if formed of gravel and puddle, particularly long races. Wooden troughs are not only expensive, but are also of short durability, and liable to leakage. Canals built of quarry-stones, hewn stones, flag-stones, and similar material, are expensive, and more liable to leakage than any other form; such work is to be confined below the water-surface only, and the joints secured by good cement mortar. The form of water-races has been investigated before; but it may be remarked here, that, in all cases of doubt, it is preferable to have the channel too large than too small — the course of it straight, instead of crooked. Closed races, iron pipes, or brick culverts, ought to be avoided by all means, because they are not only attended with a loss of power, but are liable to almost inaccessible obstructions, and are with difficulty repaired. A race should conduct the water from the pool at almost the same level from the pool to the wheel-gate; all rapid currents, rough bottom and sides, and short bends, should be avoided. Tail-races ought to be short, if circumstances permit; but if this cannot be accomplished, they are to be more secure against strong currents than the head-race; for it is commonly the case that more or less fall must be given to the tail-race, to avoid disturbance from back-water; this causes a strong current, and consequent abrasion of the banks and bottom of the race.

GATES.

On this subject we have to remark that the form of a gate can never be too simple; all complicated constructions are to be avoided. A gate is liable to be obstructed, in time of floods, by drift-wood, ice, &c.; and if there should be much machinery about it, vexatious detentions, and often serious damages, may result from it. Gates made of oak, and simply in the form of square boards, fitting well in their seats, are the cheapest and most practical form of gates; if they can be permanently submerged, their utility is still increased. Cast-iron gates, however well constructed, are generally too heavy to be manageable, and besides are liable to breakage by ice.

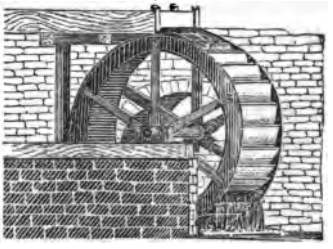
WOODEN WATER-WHEELS.

The practical execution of water-wheels is not attended with any difficulty; the effect, however, of the labour performed by a wheel depends, besides its size and the form of its buckets, on the material of which it is made. Wood is the most common material used; but it is easily perceived that, notwithstanding the small weight of a wooden wheel, the bucket is limited to certain forms; and as the form of the bucket is of the utmost consequence in the results, the use of wood for buckets is not advisable. Wooden wheels may be provided with sheet-iron buckets; but the disadvantage here is, that wood appears to effect a rapid corrosion of the thin iron, for which reason the use of that metal for wheel-buckets is not general. Where water is abundant, and a small loss of power of no consequence, wooden buckets are eminently practical. Cast-iron buckets are almost too heavy for use, and if composed of planes, in the form of wooden buckets, they are ill-advised.

Curved cast-iron buckets, however, afford an advantage in their form which cannot be arrived at in wood; but, considering their weight, and the consequent friction on the gudgeons of the shaft, their advantages, particularly in small wheels, are questionable. If any part of a water-wheel should be of iron, it is its shaft; wooden shafts are and always will be imperfect, as the fastening of the journals is difficult, and, in heavy wheels, uncertain.

Wheels of five or ten horse-power are preferable if built of wood, and provided with an iron shaft, as represented in fig. 120; this alludes particularly to overshot wheels, and those which are exposed to sudden shocks, such as forge-wheels. The master-wheel, for the transmission of power, is in this case on the inside of the journals; but it should never be fastened to the rim or spokes of the water-wheel, as wooden wheels are liable to come out of the true circle, and of course the cog-wheel will follow. This objection to fastening the master-wheel to the rim of the water-wheel is general, and applies as well to iron as to wooden water-wheels. If the cog-wheel can be kept dry, it is an advantage, because the presence of water in the cogs increases friction; but this loss is so small, that in case any inconvenience arises from changing the wheel to another place, it is preferable to submit to it, than to risk a loss of power in another place, or the danger of breaking the shaft in the journals. Where iron shafts cannot be obtained, it is of course necessary to use wood; but here, as in the previous case, it is advisable to fasten the iron cog-wheel inside of the journals. If an

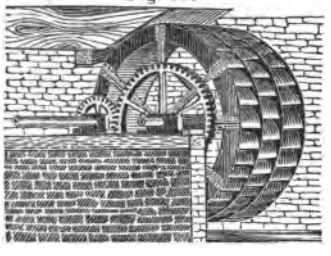
Fig. 120.



iron master-wheel cannot be applied, and wooden wheels are to do the work, the shaft of the water-wheel must be sufficiently long to bring the cog-wheel so far from the water as to keep it perfectly dry; for wood is soon destroyed under the influence of motion, pressure and water.

The width of a wooden wheel may be carried to five, and even to eight feet between the rims; but it is of doubtful propriety to make the extent of the buckets, for one length, more than four feet, as, if longer, heavy planks are required, which unnecessarily increase the weight of the wheel. As a general rule, the length of the buckets between two rims should not be more than three feet; and if the wheel is to be wider, increase the number of rims, as shown in fig. 121. Each rim is here provided with arms, and fastened to the shaft. The buckets are changed in their position, and do not form a continuous straight line. In this case there must be three gates, or as many as there are divisions; and each gate is to be a little smaller than that part of the wheel which it supplies, so as to prevent the spilling of water over the partitions, which would be a dead loss of power. Each part of the wheel is treated, in respect to the gate, as a separate wheel. Buckets three feet in length may be made of inch plank; but, if longer, their thickness increases rapidly, and five feet buckets require 2-inch plank. Of course, longer buckets require still thicker stuff, and it is therefore advisable to make six feet wide wheels, with one partition.

Fig. 121.



Small wheels are sufficiently strong if provided with

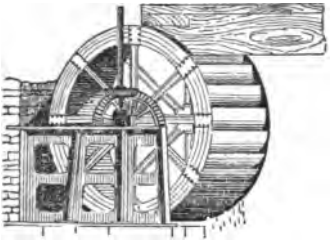
wooden arms; but wheels which are to convey a strong power, say of ten or more horses, ought to have cast-iron arms, or at least wooden arms with cast-iron fasteninga. Wrought-iron and wood do not work well together; the iron is much exposed to corrosion in consequence of the moisture, and the aciduous influence of the wood. Cast-iron, exposed to the same influences, is more durable than wrought-iron, and it should therefore be used wherever practicable. Bolts and other small parts of iron must of necessity be made of wrought-iron; and these, as well as the wood, ought to have a good covering of coal-tar before the wheel is put together. If durability is one of the objects sought in erecting a wheel, it is advisable to take well-seasoned wood, and give it several coatings of coal-tar; and if the wood should be immersed for a short time in hot or boiling tar, its durability will be augmented in a very great degree.

CAST-IRON WHEELS.

Wooden wheels, as has been frequently remarked, are imperfect on account of their form. The form of the bucket is confined to planes and angles, which renders it almost impossible to make them water-tight; to obviate these objections, cast-iron wheels have frequently been constructed. These wheels, however, are not altogether unobjectionable; they are too heavy, if very strong, and the buckets are liable to injury from accidents which are unavoidable, such as ice, drift-wood, stones, and other solid matter, which may happen to come into contact with the wheel. A cast-iron bucket cannot be so readily replaced as one of wood; and if the form of the cast-iron bucket is not much superior to that of wood, it is generally better to use the latter material, even if the remainder of the wheel

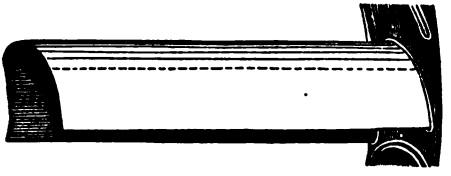
should be of cast-iron. The shaft, arms and rims of a wheel may with some advantage be made of cast-iron; still, this metal is objectionable in many respects; it is heavy if made sufficiently strong, and its brittleness renders it more subject to accidents than any other material, particularly in cold seasons, when the wheel cannot be kept free from ice. Cold, or a coating of ice, makes cast-iron almost non-elastic; and the slightest jar or concussion is sufficient to break it. If cast-iron wheels are to be constructed, it is necessary to employ the best kind of grey cast-iron, such as is known for strength and elasticity. Any impure or brittle iron, white or mottled iron, cupola iron, and particularly that iron which is cast directly from the blast-furnace, is to be rejected. In all cases, the patterns ought to be as thin as possible, and the strength of the parts is to be augmented by judiciously applied ribs, partly to diminish weight, but chiefly to produce some elasticity in the material which may resist concussion. In fig. 122, a cast-iron wheel is represented, in which the buckets are curved to the required form. Each bucket is cast in one piece, bottom and all, assuming the shape shown in fig. 123. Such a bucket may be very thin, and one-fourth of an inch thick, to three and a half or four feet long. The curved form makes it eminently qualified to resist shocks; it is lighter and more elastic than any other form of bucket. The rims of the wheel are held together and to the buckets by long screw-bolts, which traverse the whole width of the wheel; these are best placed under the convex bottom of

Fig. 122.



the bucket. The buckets are inserted into the rims of the wheel in grooves, formed by two projecting ribs, as shown in fig. 123; the grooves being five-eighths or three-fourths

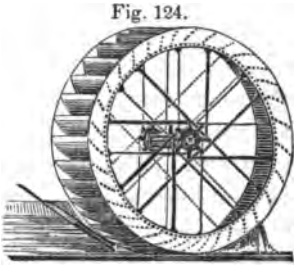
Fig. 123.



of an inch deep. Cast-iron wheels, if as light as they should be, are generally limber, and liable to break their arms by side motion; this may be in some measure prevented by applying cross-ties of wrought-iron, with screws.

WROUGHT-IRON WHEELS.

Fig. 124.



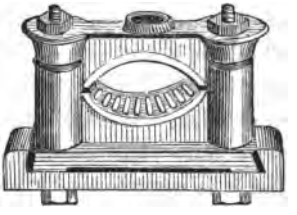
The best material for water-wheels is evidently wrought-iron; this material is light, strong, elastic, and very durable. Fig. 124 is a representation of a sheet-iron wheel. The buckets are formed of one sheet of iron, in the form of that represented in fig. 123, which, for lengths of from three to four feet, is one-twelfth of an inch in thickness. The ends of the bucket are gently bent square, so as to form an angle for rivet-holes. The rim of the wheel also is made of sheet-iron, provided with corresponding rivet-holes to the buckets. The latter are secured by ¼-inch rivets to the rims, and segments of the wheel are formed, which may be screwed or riveted

together in the wheel-chamber to form the entire wheel. The shaft may be of cast-iron; but as wrought-iron is almost as cheap, particularly for small wheels, it is preferable. Cast-iron naves or rings, to which the arms are attached, are fastened upon the shaft. If a cast-iron shaft is employed, it may be made of a large diameter, and cast hollow, and the projections for the arms cast to it; or the shaft may have the section of a polygon or a cross, and the flanges cast to it. These forms, however, are both imperfect; a portion of the shaft might break, and the whole of it would be rendered useless; while, if it were composed of sections, either part might be replaced with but little disturbance. The arms are simply wrought-iron bars, of from a half to one and a half inch round iron, according to the size and power of the wheel. These rods are fastened to the rims of the wheel, and are provided with a screw and two nuts at the shaft, for the purpose of adjustment; they are so arranged that one part of the rods, which in the drawing are marked by heavy lines, receive all the direct strain; the other half serves merely to preserve the round form of the wheel. This form of wheel includes all the elements of a perfect wheel. If the material is elastic and light, the buckets may have a correct form, and be made perfectly water-tight; and if the wheels are kept covered with oil-paint, which is the first coating put on when the iron is hot, their durability is almost incredible. The first cost of these wheels is high; but their price is still lower than cast-iron, and their expense is soon repaid by the better yield of the wheel, and the entire absence of a necessity for repairs.

PLUMMER BLOCKS.

The gudgeons of the shaft of a wheel are frequently found to run in wood, for which purpose a butt-end of locust, boiled in tallow, is selected as the most durable. Sometimes we find stones, such as basalt, granite, and other minerals of volcanic origin, employed; the compact carbonate of iron, or spheroidal balls of blue iron-ore of the coal regions, form also good plummer-blocks. All these kinds of material do well enough for light or small wheels; but for heavy wheels, cast-iron plummer blocks, lined with brass or bronze seats, such as are represented in fig. 125, are used. This block is kept in its place by wrought-iron wedges upon a cast-iron plate, which is screwed to the wooden sill. Linings of brass or bronze are liable to cause much friction, for which reason anti-friction metal—a compound of lead and antimony, with a little copper—is sometimes used. This composition is too soft and brittle to resist the pressure of a heavy weight, and therefore strips of it are inserted in the brass pan; these are bored out together, by which the advantages of the anti-friction metal and the durability of brass are secured. The cap or cover of the block must always be provided with a pot and hole to admit of grease or oil for lubrication; this should have a cover to keep out water and dust, or sand. A constant and regular supply of grease or oil is most advantageous, as we have seen before. The screw-bolts which hold these plummer-blocks in their places ought to

Fig. 125.



be strong, so as to secure these seats firmly, and resist accidental impediments to the motion of the wheels, which must be expected.

PROPORTIONS OF WATER-WHEELS.

The speed of a wheel in the pitch-line has been decided before, and is found, in those wheels which work by the weight of water, to be from six to eight feet per second. Undershot wheels, or those working by the velocity of the current, have a speed equal to half the velocity of the water. The depth of the shrouding or rim is best if narrow, because a wide rim diminishes the leverage of the current; on the other hand, too narrow rims unnecessarily increase the length of the buckets. The practical limits of the width of a rim are between six and fifteen inches. The breadth of the wheel or length of the bucket depends on the size of the rim, and the quantity of water it is to work with. We have seen that water never ought to occupy more than one-third of the capacity of the bucket; and it is not necessary to make the wheel larger than that one bucket takes less than one-fifth of its capacity for water. The number of buckets or cells is also limited; the more buckets there are, the better; this is limited by the width of the mouth of the bucket. The opening which receives the water must always be a little larger than the contracted vein of water as it issues from the gate, measured at the point where it enters the bucket. Generally speaking, we may assume that from twelve to fifteen inches is a limit from one edge of the bucket to the other; but this, of course, is not a rule. The number and size of the arms in a wheel is partly determined by the size of the wheel, but also by a consideration of stiffness. The place of fastening the arms to the rim is not of much conse-

quence, but it is perhaps best to have it at the bottom of the bucket. Particular attention should in all instances be paid to the escape of the air from the bucket; for this purpose, the mouth of the bucket is made larger than the vein issuing from the gate, and sufficient room is also provided in the bottom of the wheel for that purpose. There can never be too much room for the escape of air, care being taken at the same time that no water is wasted.

EFFECT OF WHEELS.

The labour performed by a wheel depends, as we have seen, partly on the principle on which it is constructed, on the material, and on the form in which that material is employed. The inherent power of the water itself is the quantity of water multiplied by its height; but in no case do we obtain all this power at the shaft of a water-wheel. If a paddle-wheel moves in unlimited water, we seldom obtain more than one-fourth of the inherent force of the water. If the velocity of the current in this case is 13 feet, and the surface of the submerged paddle 8 feet, the pressure upon one paddle will be $\frac{8\times13\times60\times4\times60}{4}$ = 374,000 pounds one foot high per minute, or 11·4 horse-powers.

If a wheel moves in a channel, it is more perfect, and the effect by radial paddles may be brought to one-third. If, in this case, the head is 2 feet, and the quantity of water 40 cubic feet per second, the power of the wheel is $\frac{40\times60\times2\times60}{3}$ = 96,000 pounds one foot high per minute, or 2·9 horse-powers.

A breast-wheel affords a greater yield, and may be brought to ·4, if working with close buckets. If, here, the

quantity of water is multiplied by the fall, and the sum by ·4, we obtain the power of the wheel. If the water is 40 cubic feet per second, and the head 10 feet, the power of the wheel is $\frac{40\times10\times60\times60\times\cdot4}{33{,}000}=17\cdot4$ horse-powers.

Overshot wheels may be brought to ·6, or even ·7, of the force of water. If, here, again, 40 cubic feet per second belong to 20 feet fall, the power of the wheel at its shaft may be, if well constructed, $=\frac{40\times20\times60\times60}{33{,}000}\times\cdot7=61$ horse-powers.

These calculations are of course all very uncertain, because it depends entirely on the form of the wheel by what coefficient the theoretical horses are to be multiplied. A wheel with radial paddles in unlimited water generally does not yield more than ·2; if the paddles are inclined, it yields to ·25; and if the paddles are inclined and gently curved, the yield may be brought to ·3 and ·35. An undershot wheel running in a trough, with radial paddles which do not fit well, never yields more than ·22, and from that to ·25; if the paddles are inclined, and fit well to the bottom and sides of the trough, the wheel may yield ·33 and ·35. Curved paddles yield ·35 to ·4; and closed buckets, properly curved, may yield ·5 to ·55, and even as high as ·60. A breast-wheel is very much in the same condition as an undershot wheel; it yields according to the form of the paddles, from ·2 in radial paddles, to ·6 in closed buckets. An ill-constructed overshot wheel may be reduced in yield to ·25, while a good wooden wheel ought to furnish ·4 of the force of water imparted to it. Light wheels, with properly curved buckets, yield ·6 to ·65; and if moving very slowly, say four feet per second, an overshot wheel may yield ·75.

REACTION WHEELS.

The number and variety of forms of these wheels is so great, that it is out of the question to enumerate them all in this work. We have examined this subject before, so far as it is of interest, and intend merely to allude here to some particular cases. Some few years ago, many attempts were made to introduce centre-vent wheels, on account of their alleged superiority in principle to the common reaction or centrifugal wheel. If we examine the principle of such wheels, we very soon find their imperfections, and the impossibility of their ever competing with a perfect reaction wheel. The conversion of the force of gravity into centrifugal force, which is a great advantage to the common reaction wheel, and in fact is a characteristic of it, is not only lost in the centre-vent wheel, but is a great disadvantage, as it retards the motion of the wheel. It cannot be expected that the water, in being forced from the periphery to the centre, passes radially through the wheel without partaking of its rotary motion; and if the water moves with the wheel for even a minute portion of time, it will be affected by centrifugal force, and act against the motion both of the water and the wheel.

The Scotch turbine, which is in some measure more perfect than many other forms of reaction wheel, has the disadvantage of working above water, because it has curved arms; this causes a loss of fall, at least from the level of the back-water to the discharge; besides which, if the back-water rises upon the wheel, it is much disturbed, its motion retarded, and the effect diminished. The great variety of this kind of water-motors at present in use, each claiming peculiar advantages, is an object which claims the attention of the engineer. All these claims may be easily examined

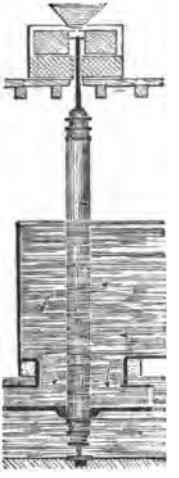
by means of the friction-brake, and the presumed or real advantages of each wheel investigated by an unfailing experiment. The argument so frequently used, that a certain wheel grinds so much corn or wheat in one hour, under a certain head of water, is in most cases fallacious; for the quantity ground depends partly on the kind and condition of the grain and millstones, the head and quantity of water, &c. All these matters, which have thus an influence upon the labour performed by a wheel, ought to be stated, if the eulogist of a certain wheel claims any superiority for it. If all such data were given, the yield of the wheel would still be undecided; and there is no way of arriving at safe conclusions but by the friction-brake.

As general conditions of a good reaction wheel, we may furnish the following data. Wheels with horizontal shafts can be of good effect only where the whole of the wheel is submerged, as every wheel must be, if we would have perfection. Another requisite is, that its motion below the surface should cause no turbulence in the tail-water, but leave it apparently at rest. Motion in the head and tail water, by which it is whirled into and out of the wheel, must be avoided; all motion which does not act upon the wheel is expended uselessly. A wheel which works better when the tail-water is raised upon it, shows that its apertures are too large; it is not suitable to that head. A good wheel is always right, and does the same amount of work in low or high water, provided the head is always the same.

Reaction wheels have their great advantages, and a good wheel, which is as yet a desideratum, would be eminently useful; but such a wheel must be simple, of good effect, and not very liable to get out of repair. These conditions, if they could be united in a wheel, would make it a valua-

ble auxiliary to farmers in the labour of threshing, grinding, &c. Where this wheel is used for grinding, it should have a vertical shaft, and be coupled directly to the grindstone, as shown in fig. 126. All gearing can be avoided in this case; for it is very easy to impart to a wheel such speed as will cause a specified number of revolutions. By referring to Table IV., we find the velocities of water from apertures; and if a wheel is properly constructed, the speed of its periphery must be nearly equal to the velocity of water belonging to the height of fall. If the wheel runs with greater speed, it consumes too much water for the labour it performs, as is the case also if it moves much slower. If the velocity with which water flows from an aperture is 25 feet, the circumference of the wheel must have a speed not greater than that; it had better be less, say about 23 or 21 feet; a slower speed than that would be disadvantageous. If a wheel under such a velocity or head is to make 100 revolutions per minute, its diameter is to be $\frac{23 \times 60}{100 \times 3{\cdot}14} = 4{\cdot}3$ feet, or 4 feet 3·6 inches.

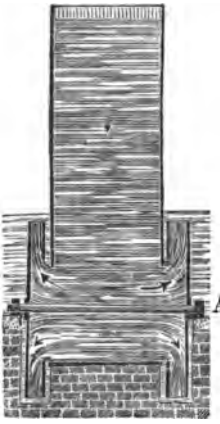
Fig. 126.



There is no objection to wheels with a horizontal shaft, provided the essential conditions of a good wheel are complied with. One of the first of these is to submerge the whole wheel, and the second, to make the conduit pipes as wide as possible. In fig. 127 we give the arrangement of a vertical reaction wheel. The horizontal axis passes through two wheels, which are supplied with water by the

pipe A. This wheel does not suffer from the pressure of the column of water upon the step, which in all horizontal wheels causes a serious loss of power. It is liable, however, to some objections; it induces loss of power in the conduit pipe, and loss of water at the two wheels, because at each wheel there must be a joint, which never is and never can be made entirely water-tight. This kind of wheel requires considerable digging below the water-level, and is on that account more expensive than any other wheels. Wheels of this kind have an advantage, in particular cases, which can hardly be sufficiently estimated; we refer to the driving of bellows, the pistons of blast cylinders, pumps, or hammers, and in fact any machine which may be driven by a crank, and which requires more than common speed. The diameter of these wheels can be regulated in such a manner as to afford any number of revolutions. If, to a water-power of two feet head, a wheel is required which is to make 50 revolutions per minute, we find, by referring to Table IV., that 2 feet head give a velocity of 13 feet; if we assume 12 feet for the wheel, its diameter must be

Fig. 127.



$$\frac{60 \times 12}{50 \times 3{\cdot}14} = 4{\cdot}5 \text{ feet.}$$

Another form of horizontal reaction wheel was constructed some years since by the author, which in many respects proved to be a practical wheel. It is represented

in fig. 128, and was built on the same principle as the foregoing, with the difference of its dipping but half, or to its axis, in the tail-water. In fig. 129 is a section of the

Fig. 128.

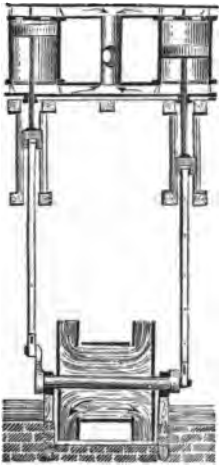
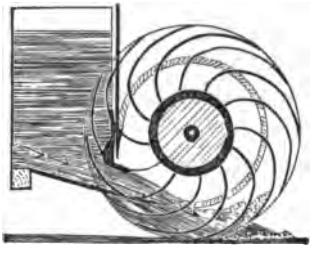


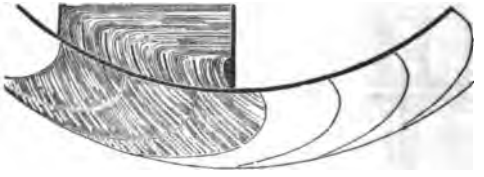
Fig. 129.



wheel, showing the form of the buckets. This wheel was calculated to discharge its water before it was raised above the surface of the tail-water. It was assumed that the water, in passing through the wheel, must pass in the line of the arrows, fig. 129; and as the last bucket emerges from the water and discharges its contents, the velocity of the latter must be = 0. These speculations were correct, but the wheel did not furnish the power calculated, which was accounted for by the water having to make a corner motion, as indicated by the arrows in fig. 128. The wheel was eight feet in diameter, and built entirely of wood, with the exception of the axis and buckets, which were made of iron.

A superior form of reaction wheel is that represented in fig. 130. So far as the principle is concerned, there is no doubt that this wheel has great advantages; it causes, how-

Fig 130.



ever, some difficulties in the execution. This wheel may have the form of a common vertical wheel, be of any diameter, and of course make any number of revolutions. It is the principle of a turbine applied to a part of the circumference of a vertical wheel. The form of the wheel makes it necessary to have all the fastenings or arms on one side, by which the construction of such wheels is very difficult; indeed, it is almost impossible to erect a large one. This wheel may have its advantages; still, it will never be equal to a well-constructed horizontal wheel, because one of the most essential requisites of a good wheel is not realized—namely, the filling of the buckets. It is of course necessary to the satisfactory working of a wheel, that all its buckets should be filled with water.

Wheels requiring a great speed, such as those at a saw-mill, which in all instances should work directly without gear, may be arranged as shown in fig. 131; these are decidedly preferable to the common small paddle-wheel. This wheel will work in back-water as well as when free from it, and uses the water to better advantage than the common wheel. If a vertical reaction wheel is to be used, this form of wheel has a decided advantage over any other

description. The application of water to the wheel is shown in fig. 132; the penstock conducts it to the buckets, which receive and discharge downwards. Any number

Fig. 131.

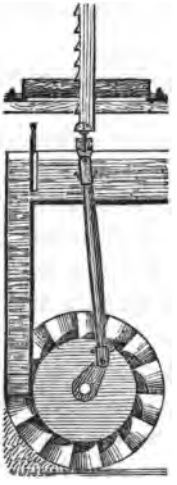
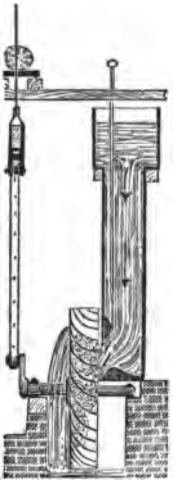


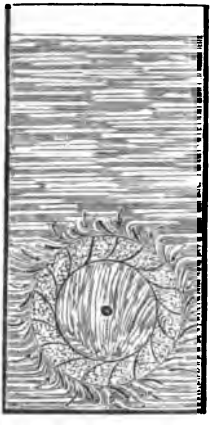
Fig. 132.



of revolutions may be given to this wheel; but in this case the circumference of the wheel does not move with more than half the speed belonging to the water from the discharge gate. If we require 150 revolutions, and the velocity of the water is 30 feet, the diameter of the wheel is to be $\frac{60 \times 30}{150 \times 2 \times 3 \cdot 14} = 1 \cdot 9$ feet.

Where great speed or many revolutions are required, as at a saw-mill, the centre-vent wheel may be employed as a vertical wheel to some advantage. The arrangement represented in fig. 133 will answer in this case better than any other. The penstock ought to reach here all round

Fig. 133.



the wheel, and the guide-curves and buckets are subject to the same law as in other instances. The speed of the rim of the wheel cannot be more than half the velocity of the water from the gates; and we are not to calculate upon more.

The number and variety of water-wheels is so great, that a particular treatise on the subject would be required to explain the points of difference between them. This much is certain, that this subject is so far cultivated, that a patent for a new construction of a water-wheel could hardly stand a rigid examination. Great as are the varieties in the forms of wheels, almost as many claims for superiority are made; and the public are in the dark as to the merits of the respective claimants. We cannot too often recommend the use of the friction-brake in cases of doubt; the instrument is simple, and perfectly safe in determining the power of a wheel; and as the amount of water is easily ascertained, the yield of the wheel is readily found.

Reaction or centrifugal wheels ought to yield at least ·75 of the power imparted to them. Good wheels will do more, and furnish ·85; but there are many that do not work more than ·25, which of course is an inferior result. The imperfections of a wheel are always in the form of the buckets; hence, if a wheel is found deficient in yield, it is advisable to throw out the buckets and put others in, and continue to change until the result is satisfactory.

STEAM-ENGINES.

It cannot be expected that we should give an elaborate demonstration of the steam-engine in this treatise; but as it is the most important of all machines for transferring power, we cannot avoid devoting some pages to the development of the fundamental principles involved. Since the time of Watt, a great variety of forms has been produced in an attempt to improve the effect or utility of these machines; but we may venture to assert, that no important improvement has been accomplished since that time, and that the economy of the machine has not been much advanced. The source of power in the steam-engine is the fuel consumed under the boiler; and all that pertains to the conversion of fuel into force, belongs to the steam-engine, and must be considered in connection with it.

THE BOILER.

The vessel to which fire is applied in order to generate steam, is in all instances constructed of metal, generally of iron. Other metals have been proposed, and copper has been frequently applied, and is still applied for sea-going vessels; but the advantages of the latter metal for this purpose are so insignificant, and the difference in price so great, that we may assert iron to be the only practicable and useful metal for that purpose. The form of boilers has undergone frequent alterations since the first application of steam-engines; but as a general rule it is now settled that cylindrical boilers for stationary engines, and tubular boilers for marine engines and locomotives, are the most useful. The simple cylinder is certainly the most perfect form for a steam-boiler, and should never be deviated from in stationary machines. A diameter of from two to three

and a half feet, seldom more than four feet, is given to the boiler, and a length varying from twenty to forty feet is the most common. The use of horizontal flues in boilers is of no advantage whatever; it of course increases the heated surface in the same space; but, when we consider the higher price of flue boilers, their shorter durability than the cylindrical, and the increased danger of explosion by the collapsing of the flues, the advantages of the flue boiler are at the best very doubtful. As, where stationary engines are employed, there is generally ample room, the argument in favour of tubular boilers, that they occupy but little space, has no force.

Flues which run the whole length of the boiler are of less service than is generally supposed; for the upper part of a round flue is an imperfect form for absorbing and conducting heat, and the lower part is of as little service for the generation of steam. In locomotives, want of room compels the use of small flues, in order to condense the necessary heating surface into the smallest space; and the large amount of fuel used in these machines for producing an effect equal to that of good stationary engines, shows how imperfectly the heat generated by the fuel is applied. Marine engines labour under the same difficulties as locomotives; but there is less excuse for small boilers in the former than in the latter case, as more space can be allotted to the boiler.

THE METAL THICKNESS

Of boilers is in some measure subject to the tension of steam which is to be generated in the boiler, and laborious experiments and calculations have been made in investigating this subject; governments have promulgated laws establishing the strength of metal in boilers, for the pur-

pose of preventing explosions. After all the labour spent in these researches, we have arrived at the conclusion that the steam-boiler is a machine which does not admit the nice execution of mathematical laws, and whose strength cannot be regulated by legal enactments. The strength or thickness of metal in a sheet-iron cylindrical boiler, supported at both ends, is generally sufficient for a high tension of steam, say 100 or 150 pounds to the square inch, if the boiler carries its own weight and the weight of water in it. For these purposes, sheet-iron one-fourth of an inch thick is in most cases sufficient. Short boilers, say of not more than twenty feet long, and two or two and a half feet in diameter, are frequently made of iron three-sixteenths of an inch thick; this thickness may be considered sufficient, but it is certainly unsafe to overload such a boiler. This is the more apparent when we consider the oxidation of iron, which is particularly strong in leaking boilers. Thin boilers are more subject to leakage than those made of thicker iron; and, if for no other reason, the iron of boilers should not be less than one-fourth of an inch thick. If the quality of the iron in the sheets is good, this size will bear almost any tension which may be put into the boiler; and if a boiler is not more than three feet in diameter, it will safely bear a pressure of from 300 to 400 pounds per square inch. Small flues, such as the pipes in locomotive boilers, are thinner; and the metal of a 2-inch pipe does not exceed one-twelfth of an inch. Iron pipes employed in marine boilers, whose diameter generally exceeds that of locomotives, are from one-twelfth to one-sixth of an inch thick in metal. In all these cases there is an excess of metal to the calculated strength, which shows that this strength is necessary for practical purposes, and that calculations which have treated on this subject are

imperfect. The metal thickness in most of these cases is subject, in practice, partly to the operations of the boiler-maker, but chiefly to the manufacturer of the metal. We can depend, to a certain extent, upon the uniformity and quality of brass and copper, if the manufacturer has been careful in his operations; but it is not so with iron — the utmost care and rectitude on the part of the manufacturer may not always secure to us uniformly good sheets. No doubt most of the explosions which from time to time startle us by their occurrence, are in a great measure owing to bad iron. Those who manufacture and buy steam-boilers ought to be well informed of the quality of iron which is to be used; and as it is not possible for them to conduct the preparation of the sheets themselves, they have to depend upon the assertions of the iron manufacturer. Hence, boiler-makers should purchase their plates from no manufacturer whose veracity is at all questionable.

The quality of iron for boilers is an object of grave importance, not only in respect to the pecuniary loss which results from boiler explosions, but on account of the many human lives which are sacrificed by such accidents, carrying sorrow and dismay into hundreds of happy homes. Many of these explosions are caused by short, or crude, imperfect iron, which it is impossible for the boiler-maker to guard against by a mere superficial inspection of the sheets. Even the working of the iron in the various operations in the workshop cannot be relied upon as a sure indication of its quality; for an iron may resist punching, shearing, riveting and forging, very well, and still be unsuitable for a steam-boiler. The quality of the iron must be attended to from the first stages of its manufacture; and, as a further security, we should see that the ore from which it is made is of a good quality. As a general rule,

we may assert that specular ore, such as that of the Missouri iron mountain, or that of Andover, New Jersey, with the hematites of Stockbridge, Conn., and Eastern Pennsylvania, are the best ores for the purpose. These kinds of ore are well qualified to make good boiler-iron; but that alone is not sufficient; for they may be spoiled in the furnaces. Above all things, hot-blast ought to be excluded in these cases; and, if legislators may be excused for interfering with manufacturing establishments, they are excusable here — it ought to be a criminal offence to employ hot-blast iron for boiler-sheets. Iron may be fibrous, and, when cold, very tenacious; but the test consists in heating it red-hot, and cooling it in cold water. If it continues tenacious, it may be considered good; if not, it is bad, and unfit for boiler-plate: no matter what may be the cause of its brittleness, it is not the right kind of material. Iron for boilers must resist the influence of heat, or it is unsuitable; hot-blast iron may be very fibrous, and even tenacious, in the bar or in sheets; but it invariably becomes brittle on being heated and suddenly cooled. Other iron may possess the same characteristics; but, as a general rule, all wrought-iron which does not retain its fibres and tenacity after being heated and cooled, is, for the subject under consideration, worthless. This is a good rule by which to test boiler-plate; and if our boiler-makers would only attend to and be governed by it, we should hear of fewer explosions for the future.

SIZE OF BOILER.

The form of the boiler has but little influence upon its effect; the size, however, governs the amount of steam which it is to make, by which we mean the surface of the boiler which is exposed to the influence of the fire. The

common cylindrical boiler makes five pounds of steam by one pound of coal, which may be brought to seven or even eight pounds by careful attention. No other form of boiler makes more steam from a pound of coal, and the only advantage of tubular boilers is their occupying less space. If a boiler is carefully attended to, it may produce steam for one horse-power by an exposure of ten square feet of surface to the hot gases issuing from the furnace; it is more safe, however, to calculate upon twelve, or even fifteen square feet for a horse-power, as what is here lost in surface is generally gained in fuel and security. One square foot of heated boiler-surface will make three cubic feet of steam, of three pounds pressure to the inch, per minute. These numbers depend in a great measure on the amount of heat in the gases which pass under the boiler; if their temperature is high, the same surface of boiler will of course furnish more steam than if the temperature is low. A high heat in the gases is always disadvantageous to economy in fuel, as is shown in locomotive and marine boilers, in which a pound of coal hardly produces four pounds of steam. The heat of the gases ought to be expended so far under the boiler, as to pass into the chimney with little more than the temperature of the metal of the boiler. As the temperature or heat carried off in the gas is the chief loss, this subject is of considerable importance in setting boilers; for the length and form of the flues, and the arrangements in the furnace, have some bearing upon it. It is evident from this that high-pressure steam causes a greater loss than that of a lower temperature. A boiler of thirty feet long and three feet diameter will afford $\frac{30 \times 3 \times 3{\cdot}14}{2} = 186$ square feet of surface, or steam for 18 horse-powers, if 10 feet are assumed for one horse-power.

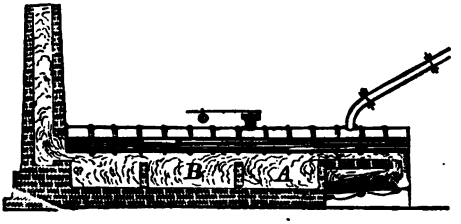
SIZE AND FORM OF GRATE.

The furnace in which the combustion of fuel is conducted, or the size and form of the grate, is of more importance than is commonly believed. Combustion is carried on to perfection only under certain conditions. To make the best use of fuel, we should burn it under the highest possible temperature, and generate carbonic acid, which is produced under the influence of the most intense heat. In this case, we obtain a mixture of carbonic acid and atmospheric air at the grate; for nearly one-half of the oxygen of the air is not consumed in the grate: this, according to all experience, is the most profitable way in which to make use of the fuel. If combustion is conducted in an imperfect manner, or at a low heat, a large portion of the fuel is converted into carbonic oxide, which affords but half the quantity of liberated heat as carbonic acid; the gas in the flue becoming a compound of carbonic acid, carbonic oxide, and atmospheric air. The plan of generating carbonic oxide to burn behind the grate, by the introduction of atmospheric air, is a roundabout method of attaining the result; for in all cases there is sufficient free oxygen in any burnt air to consume the carbon of the oxide, if the temperature of the gas is high enough to render that combination possible. The highest possible heat is required to convert all the carbon consumed into carbonic acid; the heat can never be too high for that purpose, though it may be too low. In setting a boiler, therefore, we must make such arrangements in the plan of the furnace as to carry on combustion under the highest possible heat. This requires good non-conductors of heat, such as brick, with which to surround the fire. All those arrangements by which the fuel is consumed in cool fire-

boxes, as in locomotive and marine boilers, are unprofitable in respect to fuel; fire-boxes should always be lined with brick. The form of the material is not only of importance in combustion; the colour has also an influence. Combustion is more perfect in white than in black or dark-coloured vessels; carbonic acid is formed with greater facility in a chamber composed of white material, than in one that is formed of dark matter. A black body, such as the bottom of a boiler, or a cloud of black smoke above the fire, is sufficient to suffocate combustion; that is, to prevent or at least disturb the formation of carbonic acid. The roof as well as the sides of the furnace should be of white firebrick, if we would secure good combustion. It is therefore a bad arrangement to lay the furnace in the boiler, and surround the fire by black cold iron; it is also an imperfect plan to lay the boiler's bottom above and close to the fire — combustion will never be perfect under such conditions.

In fig. 134, a plan of a furnace is shown which will obviate the difficulties arising from bad combustion; the

Fig. 134.



brick roof over the fire, and between it and the boiler's bottom, secures a more perfect combustion than can otherwise be accomplished.

The size of the grate in a furnace is determined by the

quantity of coal which is to be consumed in a certain time. A very good or a very bad grate may consume a bushel of bituminous coal per hour for every five feet of grate surface; seven feet is usual, though in some instances ten square feet is used. If combustion is perfect, a grate cannot be too large; and its size is only limited by the unpractical length of the grate bars. It is of advantage to have the grate surface rather too large than too small; for each horse-power of the engine, there ought to be at least one square foot of grate; but it will be no disadvantage if three square feet are allotted to each horse-power, as in this case the spaces between the bars of the grate may be made narrower. The size of a grate for wood may be smaller, and half of that for soft mineral coal is sufficient; for anthracite coal, the dimensions are to be increased to those enumerated. The size and number of the spaces between the grate-bars is not of much influence on the results, and practice determines both. The spaces may be very narrow for wood and pure coal; but they must be wider for impure and sulphurous coal, as the clinkers adhere to the cold grate-bars, and diminish the access of fresh air. This supply of air is a very important consideration, and, to obtain it, we can scarcely make the spaces too large; but here again there is a limit, in order to prevent the dropping of hot coals, and the consequent heating and destruction of the grate-bars.

Too much fire below the grate, or in the ash-pit, heats the fresh air, and causes its expansion to an undue degree, so that its amount of oxygen is diminished. It has, besides, the evil effect of producing or facilitating the formation of carbonic oxide gas; an evil which ought to be prevented by all means.

The height of coal or fuel in a grate depends on the

quality of fuel, and the form of combustion. Anthracite requires a height of twelve inches, while coarse bituminous coal needs but seven or eight inches; slack coal of either kind will not bear a height of more than three or four inches. This subject depends, however, very much on the management of the fire; some firemen will work a certain kind of coal eight inches high to advantage, while others require for the same coal but four or five inches. We may lay it down as a general rule, that, the lower the layer of coal on the grate-bars, the more profitable is the combustion of the fuel. The heat is never too high in the fire, and there is scarcely ever too much air passing through the fuel. The most profitable use of fuel is made when twice as much air passes through the fire as is actually required for combustion, provided the heat is sufficiently high to convert all the coal consumed into carbonic acid gas. If the layer of coal is too high, the oxygen of the air, in passing through it, will absorb more carbon, and form carbonic oxide, which gas consumes twice as much coal, and gives out but little heat; it requires a high heat to combine with more oxygen, so as to form carbonic acid. The best place to form the latter gas is in the highest heat of the grate. If carbonic oxide gas is once formed and cooled at the bottom of the boiler, it hardly burns again, but passes uselessly through the flues. If combustion is perfect, which may be accomplished by attending to these simple rules, one pound of coal may evaporate eight, or even as much as ten, pounds of water.

SIZE OF FLUES.

The gases produced in the furnace are led under the boiler, and are frequently returned in a pipe or pipes, which pass through the boiler. The length of flues is also ex-

tended by returning under the bottom of the boiler. More recently these plans have been abandoned for chambers which are formed under the boiler, as represented in fig. 134. Under long boilers, from three to four, and even more chambers are formed; the partitions between them forming bridges over which the gases escape. The space between the boiler and these bridges, as well as between the fire-bridge and the boiler, is not very particular; still, it ought in all cases to be at least twice as wide as the flue which leads from the boiler to the chimney. The size of the latter flue is to be according to the amount of fuel consumed. If the flue is too narrow, it tends to save fuel, but retards combustion; if it is too wide, it causes waste of fuel. If the size of this flue is properly determined, the boiler will work to the greatest advantage; but we are to remember that the amount of fuel consumed is not the only item in determining the size of the flue; for the manner of combustion, and the boiler surface exposed, have also their influence. As it is somewhat difficult to determine the size of the flue theoretically, it was a good plan of Watt's to interpose a cast-iron gate between the stack and the boiler flue, so as to limit or enlarge the size of the latter. This sliding gate has since been abandoned, which is to be regretted, as it was an easy and simple way of regulating the size of the flue. A reason for the abandonment of this damper was, that the iron plate was liable to get out of order, but chiefly because the fire, and consequently the boiler, worked slowly; hence it required more boiler-surface than is now generally allowed. The size of the flue is, however, an important element in the saving of fuel; we may calculate it, and also its smallest limit; but as in this case much depends, not only on the relative surface of the boiler and conditions of combustion, but also

on the peculiarities of the attendant, it is almost impossible to determine the size of the flue correctly. As a practical rule, it is advisable to make the flues at the various fire and partition bridges, in large engines, 50 square inches for each horse-power; in small engines, they should be larger. This rule makes the chimney flue too large, if half this size, and it may be made narrower; but it is best to start the boiler with a flue of half the size, and, if combustion goes on too rapidly, contract the chimney flue by the insertion of loose brick to the size which is found most advantageous. The flue will be sufficiently wide if fifteen square inches to the horse-power, and in many cases eight inches have been found sufficient; but in this calculation so many elements are required, that the practical method is the most sure and successful. All contractions, curves, and returning flues, should be avoided; the space below the boiler is never too large, because the heat works here by convection upon the boiler. Radiation from the surrounding walls is of no use; if any use is to be made of it, it causes the flues to be too narrow, and requires more draught, on account of the friction of air in narrow channels. The chambers under the boiler, as represented, are of good effect; but some partitions are required to force the air into a turbulent, mixing motion, and induce its contact with the boiler. The chimney flue, when contracted to the size which is found most profitable, is permanently fixed on some occasion when no fire is in the furnace. In setting a boiler, our aim must be to bring the hot gases into close contact with the boiler, and let this contact be extended for as long a time as possible. Narrow flues will not accomplish this object; for the motion of the gases in such flues is too rapid, and the centre of a vein of hot air may escape without coming in contact with the boiler. If the

hot gas moves very slowly, and has a whirling motion, there is a probability of its particles coming in contact, or at least there is an opportunity for the heat of the gas to be transmitted into the boiler. Gas at rest, or moving in a close column, conducts heat very poorly; but if in a disturbed condition, it is a very efficient conductor. It is therefore improper to surround a boiler with narrow flues; a large space, and arrangements to give to the gas a whirling motion, are more profitable.

SIZE AND FORM OF CHIMNEYS.

This is a subject about which we are very much in the dark; science has not afforded to us that assistance which might have been expected, and we labour under similar difficulties to those which meet us in the determination of the size of the flue: there are many and peculiar local elements which bear upon the question. It is not sufficient, in deciding upon the size of a chimney, to know the amount nnd quality of the gases, and their temperature; the kind of fuel, peculiarities of the workmen, the localities, weather and season, have all a strong bearing upon the question. We shall not allude to those calculations which have been made by eminent men, however valuable they may seem to be; they have been found deficient — that is, the rules laid down are not generally applicable. We shall arrive at a solution of this question by referring to the duties assigned to a chimney.

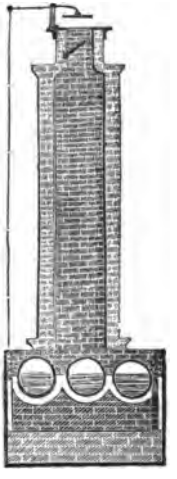
The first object of a chimney is to produce a draught; that is, a current of fresh, dry atmospheric air through the coals in the grate; this draft is produced by the difference in the specific gravity of the air inside and outside of the chimney: if the quality of the gases inside and outside were always the same, we could establish formulas for the

size of chimneys with great correctness. As it is, the elements in such a formula are so numerous and changeable, that serious objections must arise to their application. The gases inside of the chimney may be composed of atmospheric air, free nitrogen, carbonic acid, carbonic oxide, steam, free hydrogen, free carbon, sulphurous acid, and other elements. If the relative amount of these gases and their temperature were always the same, we might arrive at conclusions generally applicable; but this is not the case; the conditions to which we have referred may and do change at short and irregular intervals, and are altered as well by the gradual consumption of fuel in the grate, as by the personal qualities of the fireman. The atmospheric air outside, if not quite as variable as the gases inside, is still subject to continual changes in composition, density, and motion. Moisture, temperature, and currents of air, cause a disturbance in the laws of the current motion in a chimney.

The heat in a chimney is the principal element of motion in the gases; care must be taken, therefore, to prevent its escape before it has performed its duties. The amount of efflux of the hot gases is the measure of power; and that efflux is therefore to be regulated. The inherent heat of the gases must be preserved throughout the whole length of the chimney. The chimney should therefore be so constructed as to conduct heat badly, and the efflux is to be regulated at its very mouth. The machine for regulating the draught should therefore be at the top of the chimney; and a damper which may be regulated from below by the fireman is the best and most effective means of saving fuel and labour. In this case, the force which produces the draft is concentrated in the smallest compass, and the smallest loss may be anticipated. The form of

this damper, as represented in fig. 135, is imperfect, because it gives rise to a turbulent motion in the air; and if an arrangement can be devised by which the air is forced out in a close, compact column, it is preferable to that represented. A throttle valve, as shown, may be found advantageous; it will at least afford a more perfect form of aperture.

Fig. 135.



The height of a chimney is considered when we allude to the difference in the specific gravities of the gas inside and outside of the stack; but it is evident that the height alone cannot determine the current, because, if the velocity inside is smaller in a low than in a high chimney, we may increase its aperture, and, by that means, the amount of fresh air passing through the coal. What is lost in velocity, can be made up in quantity.

A second consideration in determining the height of chimneys, is their elevation above surrounding buildings. They must be so high as to carry off the hot gases to such an elevation as to avoid their injurious effects. Sufficient draft or current may be supplied by any height, no matter how low; but the latter consideration makes it necessary to raise the efflux of the hot gases to a certain elevation. In all practical cases, we may consider a chimney sufficiently high if it carries these hot gases to such an elevation as not to endanger surrounding buildings.

If the height is thus an entirely practical question, we have to determine the width of the chimney by considering the amount of gas which is to pass through it. If we desire the velocity in the chimney to be equal to that in the

flue, it ought to have the size of the flue; but as friction will diminish the size of the column of gas, we are to increase the width of the chimney to that of the flue, in case we want the same velocity. The extreme width of the chimney is limited by the consideration that the column of hot gas may not retain sufficient size at the mouth of the stack to prevent the entrance of cold air into its channel, which of course would diminish its capacity for producing a current. If in this instance we limit the aperture at the top to that size which is required to permit the efflux of all the hot gases generated, the excess of width below that efflux cannot injure the draft; on the contrary, it will diminish friction on the rough walls, with its consequent loss of power. The quantity of gases generated under a steam-boiler is variable; consequently, the efflux ought to be variable; and in this case, as well as in the height of the chimney; the damper at the top is the most appropriate machine for regulating the quantity of fuel consumed. With the appended damper we find, therefore, no limit to the width of the chimney. The original size of the aperture which is regulated by the damper, must be in all cases as large as that of the flue which leads the gases from the boiler to the chimney; and as this aperture is regulated by the valve, it may be made larger. When it is the object to confine the heat to the chimney, it is necessary to build it of good non-conductors of heat, such as bricks, and paint it white, so as to prevent radiation. The walls can never be too thick, and ought to be perfectly air-tight, as indeed should be all the mason-work around the boiler, in order to prevent any access of air but that which has passed through the coal in the grate.

In summing up all the elements bearing upon the size and form of chimneys, we arrive at the conclusion, that

any height will answer the purpose, and that the height which must be given to elevate the hot gases above continuous buildings is in all cases sufficient. The width of the chimney is unlimited, and a very great width could do no harm, provided the efflux of gases is regulated at its top. The loss in heat by radiation from a wide chimney is more than compensated by diminished friction. In erecting chimneys and setting boilers, there is only one object which requires particular attention, and which must be of a certain size to produce the best effect; and that is, the flue leading from the boiler to the chimney.

In many cases we see fans or blast-machines appended to steam-boilers, particularly where anthracite is the fuel. There may be no objection to these appendages in particular instances, such as for locomotives and marine boilers; but it shows a want of understanding if such contrivances are applied to stationary engines — an increased size of grate will in all cases furnish the required amount of heat. Grates for anthracite coal should be at least one and a half, or even twice as large as those for bituminous coal; if designed for wood, they may be smaller than for the latter.

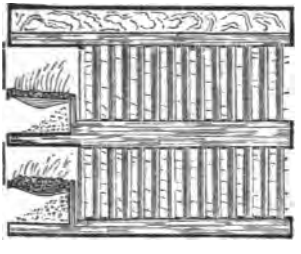
VARIOUS FORMS OF BOILERS.

For stationary engines, there is no form of boiler superior to that of the simple cylinder, without pipes or flues. In locomotives and steamboats, want of room and a desire of diminishing the weight of water in the boiler make it necessary to employ pipes, flues or tubes, to effect that object. In locomotives, a series of tubes of two inches diameter, and from ten to fifteen feet long, form all the heating surface of the boiler. The tubes are here laid horizontally, and the heat is conducted through the interior of the tube; the water surrounding its surface or exterior

diameter. The application of heat to a concave surface is wrong in principle; and the effect of those boilers which absorb a large quantity of fuel, shows their ill-calculated forms. Practical considerations make it difficult in this case to apply correct principles; still, here is a field for improvement which has been successfully entered, within a short time, by a gentleman of Philadelphia, in the construction of a locomotive boiler for anthracite coal. It is beyond our intention to enter upon the construction of locomotives; but we may remark that the common locomotive boiler provided with horizontal tubes is not the best plan for economizing fuel.

A new form of tubular steamboat boilers, which claims more than common attention, has recently made its appearance; of this form are the boilers on board the Collins line of steamers from New York to Liverpool, and on some other vessels. These boilers are provided with vertical tubes, as represented in fig. 136. The tubes are made of iron, from three to four feet long, and from two and a half to three inches diameter. The boilers are provided with two rows of fire-places, and also two tiers of tubes, one above the other, for the purpose of increasing the grate and boiler surface. We meet here with a judicious application of heat. The heat in gases is conducted to other bodies, and among themselves by convection only; this quality of gases causes the convex form of a vessel to be the most profitable in absorbing the heat of ascending gases, because the motion of the gas causes a constant change of particles on the convex body. On a

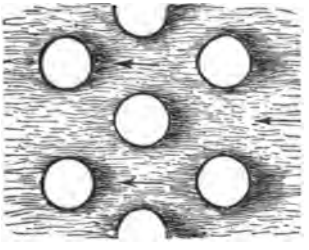
Fig. 136.



concave surface, exposed to the influence of gases in motion, but little effect is produced, because the particles of gas in the concavity are at rest. A plane surface is for the same reasons an imperfect form for absorbing heat, and it must be exposed at an angle of 45° to the current to obtain the best effect of the heating gas. In all cases, if we wish to obtain the best effect from the fuel, we should expose a convex surface to the current of hot air. If heated air ascends contrary to gravity, its motion is vertical, and the vessel ought to have its convex side directly opposed to the current. If the vessel is a cylinder, or a round tube or pipe, it must be laid horizontally, should the current be vertical. The direction of the motion of hot gases decides the position of the vessel which is to absorb their heat. If the current is vertical, the position of the pipes is horizontal; and if the current of air is horizontal, the pipes must be vertical. The current of air must always be directed so as to meet the highest point of any convex surface, and of course the axis of a cylinder or pipe, at right angles. In the above boiler, fig. 136, this principle has been partly realized, and it is the chief cause of success in these steamers. If this principle is correct — and it unquestionably is so, for gases do not convey heat by radiation — it follows that many of our common cylinder boilers are set incorrectly, and that a far better result may be obtained if the flues of the boiler are directed so as to make all the heated gas move vertically, instead of conducting it in horizontal flues. The application of this principle may be attended with some difficulties in practice; but the advantages arising from it so far outweigh these difficulties, that it will be found profitable to employ expensive vertical tubular boilers for stationary engines, in case no other form of boiler can be applied to realize the above principles.

Tubes or other vessels containing water must be placed so that the hot gases play around the outside. If we lead a current of air around a cylinder, we may observe that a particle of air plays but a short time on its surface, when it gives way to another. This experiment may be easily tried by putting a pipe in a strong draught of air, in which a little dry flour is diffused; we see then that after a particle of the flour touches the pipe once, it is thrown off from it, to make room for the next following particle. The particles play almost all around the cylinder, and a concentration or increase of density behind the pipe is the consequence.

Fig. 137.



In fig. 137, this motion of particles is illustrated, which shows in the mean time that the relative position of the pipes in their range is not indifferent, and that the distance of one from the other must be related to their diameter. The advantages arising from the position of pipes in offering their convex surfaces to the current of hot gas are so clear and comprehensive, that the erroneous application of tubes in the locomotive boiler, and also that of larger flues in marine and stationary boilers, is too evident to require any further demonstration. We earnestly recommend the adoption of this plan in the steamers which ply on the great rivers of the West, not so much on account of the saving of fuel, as that is generally cheap; but because, with good boilers of this description, explosions would be avoided. The objection that may be raised to these boilers on the ground of expense, will be found of less weight if we consider their great advantage over any other form of boilers in the saving of fuel In

constructing such boilers, it is advisable to make the pipes as short as possible; they are to form a range of columns directly opposed to the current, avoiding all plane surfaces, and, if that cannot be done, directing the current of hot gas obliquely against it. One large, or, what is preferable, a number of small furnaces, ought to be made use of, in order to furnish an abundant surface of grate.

The application of this principle to common cylindrical boilers appears at first to be attended with some difficulty; still, there is a way of accomplishing the object. We will endeavour to explain this by inserting the illustrations, figs. 138 and 139. The furnace, or furnaces, may be at one end of the boiler, but must be separated from it by a brick roof. The hot gas is led vertically around the boiler, in the direction of the arrows, and unites above the boiler in a common channel, which runs the whole length over the top of the boiler, as shown in fig. 139. A series of flues lead the hot gas. The sum of the areas of these flues

Fig. 138.

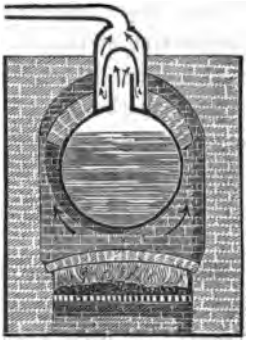
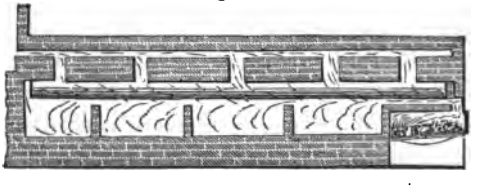


Fig. 139.



is not larger than the usual width of the flue leading from the boiler to the chimney in common cases, as has been

shown in previous pages. The steam room in the boiler is small in this case, because the water-level is high; it is therefore necessary to append a dome to the boiler, in order to make the necessary steam room. The application of a dome is found advantageous in all instances, and affords an unexpected saving of fuel in common cases. This saving is chiefly caused by freeing the steam of some of its moisture, or that water which is commonly carried along mechanically by the steam. In this case, the water which is carried through the central pipe is deposited in the jacket of the dome; and this jacket may be surrounded by the top flue, for the purpose of evaporating that water, without any danger of explosion; for the hot gases, before they arrive at this end of the boiler, are well cooled, and, if the dome is surrounded by a thin layer of brick, so as to prevent the immediate contact of these gases, the steam may be made anhydrous, and afford, besides a saving in fuel, a better yield in the engine.

ANHYDROUS STEAM.

This subject does not generally receive as much attention as its importance demands. Our boilers are usually deficient in steam room, which causes the water to rise with the steam, thus inducing a loss of power in the engine, and a greater consumption of fuel. This evil is particularly apparent in locomotive boilers, and in cylindrical boilers with horizontal flues, because they afford a large quantity of steam, which, in rising from the water with great velocity, causes ebullition, and, in its motion, carries particles of water along with it. The heat of the water thus carried off is entirely lost, as this water cannot produce any effect; besides, it obstructs the passage of the steam, and is a hindrance to the motion of the piston in the engine cylinder.

It causes the pumps to do a vast deal more work than is actually necessary, and is an indirect source of explosions. A dome on the top of a boiler, in which the steam is raised and made to descend vertically, is the best method of producing anhydrous steam. The moist steam, in being directed downward, will precipitate the particles of water with great velocity, and gravity will hold it at the bottom of the vessel into which it is precipitated. Arrangements for this purpose may be made in a great variety of forms; we represent one in fig. 140, in which the arrows indicate the motion of the steam. A small pipe is to be appended at the bottom of the dome, for the purpose of tapping off the condensed water as it rises, so as to prevent its being again carried off by the steam.

Fig. 140.

BOILER EXPLOSIONS.

Explosions have been assigned to a variety of causes, all of which may perhaps operate in producing the result; but from the great number of these disasters which have taken place, there ought to be no difficulty in detecting and pointing out the chief cause. The majority of explosions occur when the boiler has been for a short time at rest, and the generation of steam is sudden; or they happen when the capacity of a boiler for evaporation is taxed beyond its limits. The cause of explosion is in both cases the same; in the first, it is the steam at rest during the interval of stoppage; in the latter, it is the highly-urged fire, which heats the metal at the steam-room, or even below the sur-

face of the water, to a high degree. The metal in this case absorbs the heat, because the layer of steam nearest to it and at rest is a bad conductor of heat. When, in this condition of rest, steam is suddenly drawn from the boiler, if it is set in motion, all the heated surface of the boiler is directly covered with a spray of water, which expands and produces a large quantity of steam, which in endeavoring to escape will break the strongest boiler. It is not necessary to show the irresistible force of such steam; but if the metal is intensely heated, no safety valve, fusible metal, or any other contrivance, will prevent explosion. The suddenness with which steam is generated, causes all preventives to be useless. Assuming this as the true hypothesis, we readily find the means of preventing explosions. If the accumulated heat in the metal is the cause of explosions, we must prevent that accumulation, which is most effectually done by not overloading a boiler; that is, by not requiring it to make more steam than it has capacity for, and by never shutting the safety-valve entirely, if the engine is at rest, even if the pressure in the boiler is less than required; but we should permit the escape of a small portion of steam, as it will keep the steam and water in the boiler in motion, and avert the danger arising from a state of rest.

It has been asserted that low water in a boiler is in most cases the cause of explosion; but the evidence deduced from actual explosions shows that many of those explosions occurred when the boilers were well supplied with water. A scarcity of water may increase the danger, but it cannot be regarded as the only cause of explosions. If the steam in a boiler, or a portion of it, is at rest, the metal surface may be heated to a high degree; and that heat is given out suddenly in case water is brought into contact with it

Such high heat as to form spheroidal particles of water cannot be expected in a boiler; but, if it should happen, a white heat of the boiler would not prevent the sudden formation of steam, if the steam or water is set in motion. If the steam and water are at rest, the metal surface is covered with a layer of steam at rest, which may extend below the surface of the water. We may observe this in a red-hot iron concave vessel, wherein water evaporates very slowly if at rest, but suddenly if in motion. If the common precautions against the explosion of a boiler are observed — that is, good iron and sufficient strength, a good reliable safety-valve, the boiler not overworked, and the water kept above the fire-flue — there is no danger whatever, with ordinary care on the part of the fireman or engineer, if we keep the steam and water in motion. In case the engine is not at work, the safety-valve must be opened, not for the purpose of reducing pressure, but to produce motion. High pressure, simply, is not and cannot be the cause of explosion; for a cylinder boiler of $\frac{1}{4}$-inch thick iron is in all cases strong enough to resist any practicable pressure. A boiler may explode even by a very low pressure, a pressure infinitely below the strength of iron, if a large bulk of steam is suddenly generated, which cannot escape gradually. It has been found that the sudden liberation of gases from explosive mixtures will break the strongest metal vessel. Fulminating powder will burst a gun without dislodging the ball. A high tension in a boiler never will nor ever can cause an explosion; that is, if the tension is not driven beyond the strength of the boiler. A rent or leak may happen, but an explosion cannot be the consequence if the tension rises gradually. A heavy load of gunpowder will not burst a gun, if it is consumed gradually; but if a small quantity should be ignited

suddenly, as might be done by inserting one or more percussion caps in the load, the best gun would inevitably burst, even if it contained no ball or shot.

INCRUSTATION.

As the water by which boilers are supplied contains in most instances soluble concrete matter, from which the water is freed by evaporation in the boiler, there remains a solid residuum, which covers the sides of the vessel, causes loss in fuel, diminishes the capacity of the boiler, and may be the cause of its premature destruction. Muddy or turbid water rarely forms a solid precipitate; it deposits mud, which in accumulating is injurious, but not to the extent of matter actually dissolved in water, and precipitated by the evaporation of the solvent. All water contains a greater or less amount of soluble substances, such as sulphate of lime, carbonate of lime, and the other salts of lime, with the alkaline earths generally; it contains also salts of the oxides of iron, manganese, lead, and the alkalies, and in fact may contain an innumerable variety of substances in solution. In evaporating a portion of the water, a part of these substances is precipitated, and forms in many instances a solid covering over the interior of the boiler, which often adheres pertinaciously to the metal. Many remedies for this evil have been proposed, some of which under particular conditions have been found to be of use. A universal remedy against this evil does not exist, and probably never will; but we are enabled to recommend a plan as the most generally useful. Charcoal made from hard wood, broken into lumps of a quarter to half an inch in size, from which the fine dust has been carefully sifted, will, if thrown into the boiler, effectually prevent the formation of any solid concretion on the metal.

The quantity of coal is of course to be in proportion to the quantity of water which the boiler evaporates, and in proportion to the amount of impurities contained in the water; for the charcoal will not affect more than a limited quantity of matter. The charcoal here operates partly mechanically in scouring the metal, but chiefly chemically in condensing the impurities in its pores. It is known in chemistry that charcoal possesses the power of condensing oxides of metals from solutions, which applies particularly to those metals which decompose water, without forming soluble oxides. In this case, we deprive the solid matter of its solvent, and the only thing we want is something for which the precipitated matter has a greater affinity than it has to metal; for which purpose, charcoal is better adapted than any other material with which we are acquainted. It cannot condense the salts of the fixed alkalies, as those of potash and soda; but it will effectually absorb all salts of lime and the alkaline earths, the salts of iron, and almost all other heavy metals. The capacity of charcoal for this purpose is therefore limited; it absorbs a certain quantity of matter, but no more; and the incrustation will go on again, if the coal is not renewed in time. The quantity used in common cases, however, is not great; two bushels of coal will protect a boiler of twenty or thirty horse-power effectually for four weeks; after which the old coal should be removed, and a fresh supply charged. By these means it is found that a boiler may be kept free from the smallest particle of sediment. All other means proposed to prevent incrustation, such as clay, saw-dust, ammonia, coal-tar, &c., may be useful in particular cases; but they are not of such general utility as charcoal. If salts of potash or soda are dissolved in water, as in that of the ocean, nothing will prevent the precipitation of solid mat-

ter, if the concentration of the water is carried too far. In this instance, the periodical blowing-off of concentrated water is required, in order not to precipitate any salt. The blow-off pipe ought to be in the lowest part of the boiler, for which purpose the lowest part of the boiler's bottom is concave; no fire ought to be applied to this part of the bottom, in order to prevent agitation and the formation of a solid crust.

We recommend the use of charcoal in the proposed form as a preventive against the incrustation of marine boilers, as well as those of locomotives; we are confident it will be found effectual.

THE ENGINE.

The dimensions of the engine depend in a great measure upon the power which it is to possess. A desire of improving the whole machine, or portions of it, by ingenious engineers, has produced a great variety of forms; and we may confidently state, that of the many thousands of engines in operation on the earth, no two are alike. Since the time of Watt, no valuable improvement has been effected; all the important principles of the engine, and the laws of the generation of steam, were known to and judiciously applied by him. The economical effect of our present engines is, generally speaking, behind those of Watt's manufacture, clearly showing that no actual progress has been made.

Since the introduction of the steam-engine, it has been applied to a great variety of uses, which will account for the multitudinous forms it has been made to assume. Great ingenuity has undoubtedly been shown in adapting the engine to all the various claims made on it. But this is all we can say; all or most of our engines consume too much

fuel, ranging from four to thirty pounds per horse-power per hour. Where fuel is almost superabundant, as is the case at present in some of our Western States, the amount of fuel consumed by the engine is not of much consequence; a steamboat on the Ohio river may burn thirty pounds of coal to the horse-power without incurring any serious expense. This waste of fuel, however, is a disadvantage to the community, if not to the individual; and it ought to be the aim of engine-builders to attain perfection in the machines under their charge.

SIZE OF CYLINDER.

On the virtues of some engines which showed superior results, certain sizes of parts of the engine have been prescribed, which have been in use as general rules. We shall mention some of these rules, with the caution, however, that they cannot be relied on; for it is evident that certain forms and sizes may be perfect in one case, and unsuitable in another. We are under the impression that one of the causes of the slow progress in the steam-engine, has been the scrupulous imitation of certain forms and sizes. Imitations tend, in most cases, to retard progress, and, if pertinaciously adhered to, are productive of stagnation.

The velocity of the piston in the steam-cylinder, in large engines, is assumed to be most correct if from 4 to 5 feet per second, and 2·5 feet and upwards in small engines. There is no good reason why this velocity should be a rule. Steam rushes from an aperture with a velocity of almost 1700 feet. It is therefore evident that the velocity of the piston can have but little effect on the action of the steam; it cannot materially increase by slow motion, or diminish by rapid motion, the yield of power from a given quantity of steam. The velocity of the steam-piston decides the

speed of the pumps, and other parts of the engine. Pumps can be driven to advantage only by a certain speed; and if the pumps are directly connected with the motions of the steam-piston, the velocity of the latter must be confined within certain limits.

Another law which regulates the velocity of the piston, is the law of impact. If the parts of an engine move too fast, impact will cause vibrations, which diminish the effect of the engine. If the feeding and exhaust valves of the cylinder are too narrow, or work too slowly, the speed of the piston is to be limited accordingly. All these various matters, which thus exert an influence upon the speed of the piston, are not necessarily connected with that speed; the pumps may be detached from the engine, or may be driven by a speed independent of that of the piston. The parts of the engine may be so arranged as to diminish impact, which is the result of velocity and mass; if we diminish the latter, we may increase the first. The valves for transmitting the steam from the boiler to the cylinder can be so regulated in motion and size, as to offer no serious obstacle to the passage of steam; and in this case the velocity of the piston has no relation to these valves. The velocity of the piston may be increased without disadvantage to the effect of the engine, if the pumps have their own peculiar speed, if the valves offer no impediment, and if the weight of the moving parts is comparatively light, and the frame heavy and strong, so as to prevent vibrations. If the velocity of the piston is greater than the speed commonly adopted, it cannot be disadvantageous, as it diminishes the quantity of steam lost in leakage between the piston and the cylinder.

DIAMETER OF CYLINDER.

The diameter of the cylinder has been subjected to certain rules, relative to the stroke and power of the engine. The stroke or length of the cylinder is assumed in English machines to be two or three times its diameter. This rule is, however, at present but little observed; we find the diameter extended to a greater length than the cylinder, and also find cylinders which are six times the length of the diameter. The particular application of the engine, and the mode of feeding, determine, in most cases, the length and diameter of the cylinder. If an engine is to make many revolutions, the length of the cylinder is diminished, and its diameter increased; and if the revolutions are limited, the length is increased, and the diameter diminished. Where expansion of steam is applied, the length of stroke is generally greater than where the whole pressure of the steam is used to the full extent of the cylinder. Our vertical marine engines generally work with a long cylinder, in order to increase the length of the crank with which paddle-wheels of large diameter are generally driven. Where marine engines drive a screw propeller, the stroke is necessarily short, because the number of revolutions is great. The diameter of the cylinder is therefore governed by the use to which it is intended to apply the engine. If any principle is involved in determining the diameter, it inclines to a large diameter and short stroke. This implies, however, the use of large steam-ways; if the loss of power in the steam-ways is not considered, serious losses in power may occur. A short stroke, in addition to the advantage of decreasing the amount of leakage and friction, (because its capacity increases with the square of

the diameter, and the first only as the diameter,) has the advantage of being subject to less impact in the movable parts.

SIZE OF STEAM-PIPES.

The diameter of pipes leading from the boiler or boilers to the cylinder, is governed by the capacity of the cylinder, and the amount of steam consumed. The diameter of these pipes should never be less than one-fifth of that of the cylinder, and no harm is done if it is larger; this makes the section of the pipe one-twenty-fifth of that of the section of the cylinder. The length of these pipes should be as limited as possible, to prevent condensation of steam, which not only causes a direct loss of heat, but by which the water formed passes into the cylinder, and obstructs the free motion of the piston. It is a better arrangement to let this pipe ascend, inclined from the boiler, so that the condensed water may return to the boiler by its own gravity. If this cannot be effected, it is advantageous to insert a priming tube between the pipe and the cylinder, so as to dry the steam before it enters the latter. In most cases, a simple pipe, as represented in fig. 140, is sufficient for the purpose. If these pipes are necessarily long, they ought to be covered with a good non-conductor of heat, such as a second pipe of thin sheet-metal, leaving a space of one inch of air at rest between the two pipes; or they may have a covering of soft wood, canvas, rope, cotton, or wool; which coverings may be painted white, or polished, to diminish radiation.

SIZE OF STEAM-WAYS.

Steam-ways are a prolongation of the steam-pipe, and ought to have the same size. Want of room and other

inconveniences frequently prevent the application of large-sized steam-ways, to the injury of the effect of the machine. If the change of motion of the piston at each termination of its stroke is accomplished, the whole section of the steam-ways ought to be thrown open at once, injection and exhaustion ought to be simultaneous, and no gradual opening and shutting of the valves ought to impede the motion of the steam. If we consider the steam-ways as a prolongation of the pipe, we are easily convinced of the necessity of their being large.

VALVES.

The oscillating motion of the piston renders it necessary to inject the steam alternately, first on one side, and then on the other; or, where but one side of the piston is at work, it is necessary to interrupt the current of steam, in order to admit of the return motion of the piston. The most common form of valve in use is the poppet valve; it is used in marine engines almost exclusively, and in a great measure for stationary engines: locomotives work sliding valves. The poppet valve is a more perfect form than any other kind of valve, and is of assistance in arriving at a correct form of steam-ways; for it admits of being suddenly opened or closed, affording at once a large area for the passage of steam. These valves, as commonly applied, will not bear rapid motion without being injured; the concussion caused by being suddenly thrown into their seats, is destructive to them, and injures that tightness of fit which is desirable.

The sliding valve is a more practical valve than the above; but, in its simple form, it is incorrect in principle. This valve always fits closely in its seat; it will bear any

speed of the engine without injury, if it is moved by the common eccentric. The sliding valve is certainly the most perfect valve, if its motions can be regulated so as to open the valve suddenly and sufficiently. Such forms of valves as circular or rotary valves, cogs, and throttle valves, are of no use in changing the motion of the piston. Expansion valves are subject to the same objections as the above valves. The poppet valve is extensively used for this purpose; but its superiority by no means follows as a necessary consequence.

MOTION OF VALVES.

The motion of the above valves is generally produced by an eccentric from the crank-shaft. This eccentric causes a motion of the same nature as the crank, and, if it is attached to a sliding valve, will cause its motion to be extremely slow at both ends of the stroke. In moving poppet valves, such parts of machinery are interposed between the eccentric and the valve as to cause the latter to perform the required motion. In some cases, particularly in the Western States, the valves are moved by an irregular eccentric, or cam, which is fastened to the main shaft, and performs the motions of the valves directly. These cams are necessary in using the expansion valve, because it is to make, under all circumstances, sudden changes of motion. The common eccentric or crank is the most perfect motion, so far as practice is concerned, and if, by its application, means can be devised to cause a sudden opening and closing of the steam-ways, this eccentric will possess very great advantages; for it is durable, and its motions are easy, causing no noise or vibration.

PUMPS.

One or more pumps are generally appended to an engine. A high-pressure engine, of which description are locomotives and many small stationary engines, is generally supplied with but one pump, which is the supply-pump for the boiler; though in many cases two pumps for this purpose are appended, to guard against delay and danger from an accident, to which pumps, and small ones in particular, are very liable. The size of the feeding pump is always twice, and sometimes four or more times as large as is required for the supply of the boiler. In producing one horse-power, forty pounds of water per hour are consumed. A pump must therefore furnish at least that amount of water, and no harm is done if it supplies three times as much. If we multiply the number of horse-powers by 40, and that again by 3, and divide this by 60, we obtain the pounds of water used in one minute; at least the capacity of the pump must be such as to furnish that amount of water. Where more than one feeding pump is employed, each of them should have sufficient capacity to supply the boiler in case an accident happens to the other. Feeding pumps are in many instances troublesome appendages to the engine; and it is a gratifying indication of some progress in the art, that many engines are now constructed without having the feeding pump attached. It forms in these cases a separate machine, is supplied with steam, and may be made to work as circumstances require, injecting more or less water according to the wants of the boiler. We consider this a decided improvement, and have no doubt that, rfter all the pumps are separated from the engine, it will become more manageable, and be relieved from the complicated laws by which it is at present governed.

AIR-PUMPS.

Engines working by condensing the steam as it comes from the cylinder, are supplied with an air-pump. This pump works but little air; that contained in the water, and liberated in boiling, forms the bulk of it. The chief object of this pump is to extract the injection water from the condenser, or, in case condensation is carried on without injection, to extract the condensed steam and the air from behind the piston. The size of the pump is generally from one-half to two-thirds of the diameter of the steam cylinder, and half the stroke of that cylinder. This gives the pump a capacity of from one-fifth to one-eighth that of the cylinder. This capacity depends on the quantity of water injected; and as this again depends on the quantity of steam injected, the dimensions of the pump are related to the latter. If the engine works with expansion, the pump may be smaller than if the cylinder works with full, and particularly with high-pressure steam. Generally speaking, all pumps connected with the steam cylinder are nuisances; and if we refer to the principles of water-pumps, as expounded in former pages, we find that pumps are in the wrong place if connected with the engines. Pumps, to work well and profitably, must work by themselves, free from the influence of other machinery. This alludes more particularly to large than to small pumps, and especially to the air-pump, because it is to throw a large quantity of water, the turbulent motion of which by a fast-working engine causes a great loss in power. The separation of the air-pump from the engine will be a vast improvement, and relieve the steam cylinder from many embarrassments to which it is at present subject.

COLD-WATER PUMP.

The condensing apparatus requires a large quantity of water, which is supplied by the cold-water pump. This is generally a suction pump, and draws the water from a well or pool, or, as in a steamboat, from the element in which the latter moves. The quantity of water which is furnished by this pump is in some measure related to its temperature; but as this can be assumed to represent a mean temperature of 50° or 60°, and as the water extracted by the air-pump from the condenser is not heated beyond the temperature of 120°, or at least ought not to be, the quantity of cold water used is equal to 15 times the water injected into the boiler. One gallon of water converted into steam will heat five gallons to boiling without forming steam; we need here the difference, or $120° - 60° = 60$; and as 180° are required to heat from freezing to boiling, it requires $\frac{180}{60} = 3$ times as much, or 15 times the water converted into steam. Of course the pump should have a greater capacity than this, to provide against losses; and we accordingly find such pumps of one-twenty-fourth or one-twentieth of the capacity of the steam cylinder for low-pressure steam. The remarks made with respect to other pumps apply here with more force than in those instances; for this pump is very liable to disorder, and causes frequent delay and vexation. It ought to be separated from the direct motions of the engine.

INJECTION VALVES.

The water raised by the last pump accumulates in a reservoir, and is conducted thence into the condenser by a pipe, provided with a valve, or stop-cock. The quantity

of water injected must not be beyond the capacity of the air-pump; the smaller the quantity of water used, the better. The degree of heat in the water thrown off by the air-pump is the measure by which to regulate the injection. If this water is too hot, more cold water is injected; if too cold, or if the air-pump cannot work all the water which is injected, the injection cock is turned so as to diminish the quantity of water.

HEATERS.

To most of the high-pressure engines a heater is appended, which receives the cold water from the well. It forms a reservoir, which is placed either above the engine or the boiler, or in some other convenient place. Through this basin, which is generally made of sheet-iron, the exhaust-pipe from the steam cylinder is led, and the feeding water for the boiler is thus heated previous to being injected. A heater may do good service, and save from ten to fifteen per cent. of fuel, if well constructed. It does not require particular attention to heat this water to a sufficient degree; but it is worthy of remark that a short horizontal pipe will do more service than a long vertical one. The water from this heater is drawn out by the feeding pump, and forced into the boiler near its bottom. If the water in the heater is too hot, the pump is liable to work badly, because the steam formed by the hot water fills the pump-works by contraction and expansion, and prevents the hot water from entering. To prevent these disturbances, a stop-cock is appended to the pump to let out air and steam in case the pump will not do its duty; and for similar purposes, a check-valve is interposed between the pump and the boiler, to prevent the heating of the water in that pipe, and consequent dead play of the pump. These heaters

may be brought over the boiler and worked, with great advantage to the engine. If over the steam-boiler, a horizontal heater is laid in the form of a small boiler, and the exhaust-pipe led through it. That heater is connected with the steam-boiler by a large pipe, three or four inches wide; this pipe reaches nearly to the bottom of the boiler, near the fireplace. When the cold-water pump forces water into the heater, a small cock is opened at the top to let out any steam or air which it may contain; and in the mean time, the communication between it and the boiler is closed by a cock, or, what is preferable, by a valve. The heater is now filled with cold water, and, when nearly full, the pump is disconnected, the air-cock at its top closed, and the communication between it and the boiler restored. As long as the water in the heater is colder than that in the boiler, it will not enter the latter; but when the exhaust steam heats the feeding water so far as to bring it to the same temperature as that in the boiler, it freely enters. If the exhaust steam does not furnish sufficient heat, a small pipe leading from the steam-boiler to the top of the heater, and which is regulated by a stop-cock, may be opened, which furnishes steam, or, what is the same, pressure, upon the surface of the feeding water, and it will sink by its own gravity into the boiler. This arrangement is the cheapest form of feeding a boiler; it does not absorb more power, in the worst case, than an equal volume of steam to that of water. Such a heater ought not to be too small; it should never be less than one-twentieth of the capacity of the boiler. The stop-cock on the top of it may be replaced by a small safety-valve.

THE PISTON-ROD.

The piston-rod should in all cases be made of steel; but, though this is given as a general rule, it is not observed in large engines, chiefly because good steel rods of the required size cannot be obtained. The size of a piston-rod is soon strong enough, so far as the strain on it is concerned; but its durability depends upon its liability to vibration, which ought to be prevented by all means, as it injures the close fit of the packing in the cylinder and stuffing-box. As a practical rule, the diameter of this rod may be one-tenth of that of the cylinder; it is increased, in small engines, to one-fifth of that size. In high-pressure and horizontal engines, the piston-rod is liable to overheating, by which the packing of the stuffing-box is injured; this overheating is effectually prevented by directing a small stream of cold water upon the rod, near the stuffing-box.

THE CONNECTING-ROD, OR PITMAN,

Is frequently made of wood, mounted with wrought-iron, particularly in the horizontal engines of the Western States. Most of the engines at present manufactured in good establishments, have wrought-iron connecting-rods. The oscillating motion of the rod between the crank and the piston-rod renders it particularly liable to vibrations, against which it should be protected either by sufficient strength, or by braces; in this respect, the wooden rod has advantages over that made of iron. The connecting-rod should be at least three times as long as the stroke of the engine, or six times as long as the crank; in horizontal engines we find it considerably longer, and in vertical engines it is shorter.

THE CRANK

Is in most cases made of cast-iron. In locomotives it is exclusively, and in marine engines frequently, of wrought-iron; in the latter it is also found of cast-iron, mounted and strengthened by wrought-iron. Cranks made in one piece with shaft and crank-pin, are not of much advantage; a little iron may be gained in weight, but its quality and strength cannot be depended upon as well as if the parts were made separately, and brought together in a judicious manner.

THE FLY-WHEEL

Is generally made three or four times as large in its diameter as the stroke of the engine. The weight of this wheel is variable, and depends on the speed of the engine, and the manner in which the steam works; it is also regulated by the purpose for which the engine is intended. If the horse-power of the engine is multiplied by 2000, and this divided by the square of the wheel's velocity at the periphery, in feet, per second, we obtain the weight of the wheel in cwt. This weight answers for high-pressure engines, driving saw-mills, grist-mills, and similar machinery, where uniformity of motion is not strictly required. For cotton-mills, this weight should be multiplied by 2; for a particular, uniform motion, by 2·5 or 3; and for rolling-mills, by 4.

POWER OF THE ENGINE.

If steam is admitted from the boiler into the cylinder, it never enters the boiler with its full tension; and we may conclude that the average of our high-pressure engines have not more than half of that pressure in the cylinder

which is in the boiler. This difference is not so great in well-constructed engines; and in many instances we may calculate upon ·9 of the tension in the cylinder to that in the boiler. If the valves of the steam-cylinder are so arranged as to fill the whole cylinder, we are of course entitled to the whole force of the steam. If steam of 100 pounds pressure to the square inch enters the cylinder, and continues to enter until the cylinder is filled, it presses upon every square inch of the movable piston with a force of 100 pounds; and if we multiply the velocity of the piston by the pressure upon it, we obtain the horse-power. This operation would be very simple, if no condensation in the pipes, no loss in the valves, and no leakage and condensation in the cylinder, should occur; here we have to subtract the friction of the valves, of the piston, piston-rod, fly-wheel bearings, and others; the power consumed by the feeding-pump, the air-pump, and the cold-water pump. All these considerations bring a considerable coefficient into calculation, which diminishes the labour performed by an engine. A great deal depends in this case on the execution of the engine; in fact, a well-made engine, no matter how incorrect its principles may be, is preferable to an ill-made engine of the most correct principles. A well-made condensing engine will furnish ·6 of the power generated in the steam-boiler; small engines, ·5; high-pressure engines, working full stroke of steam, ·3 to ·4. We may in some instances multiply the surface, pressure, and velocity of the piston, and multiply by one of those coefficients; but this never affords an approximation to the truth; it is mere guess-work; no coefficient can be developed which is applicable here. It is altogether out of the question to establish a general formula which is to express the power of steam-engines; the friction-brake is here, as

well as in other cases, the most safe and simple means of ascertaining that power. Some approximation to the actual power may be formed by referring to the boiler-surface exposed to the hot gases; and in case the fire is very intense, and the gas disappears under a high temperature in the chimney, we may adopt 8 square feet of boiler-surface to the horse-power; in common instances, 10 feet; under good management and slow combustion, 12 feet; and, if the boiler is heated by waste heat, as in iron-works, from 18 to 20 feet for one horse-power. In this estimate, well-made engines are presumed.

The use of fuel is another element by which to ascertain the power of an engine; but if we consider that a good Cornish pumping engine consumes but 2 pounds of coal per horse-power in an hour's time, and that well-made small high-pressure engines consume 20 pounds in the same time for the same power — a poorly made or poorly kept engine, 30 pounds of coal for the same purpose — we find the limits for determining the power of any engine by these means, too much of an arbitrary operation. A steam-engine at the Gloucester cotton-mills, near Philadelphia, uses but 4·5 pounds of coal per hour, per horse-power; while an engine of equal power, at a certain iron-works, consumes 25 pounds for the same purpose.

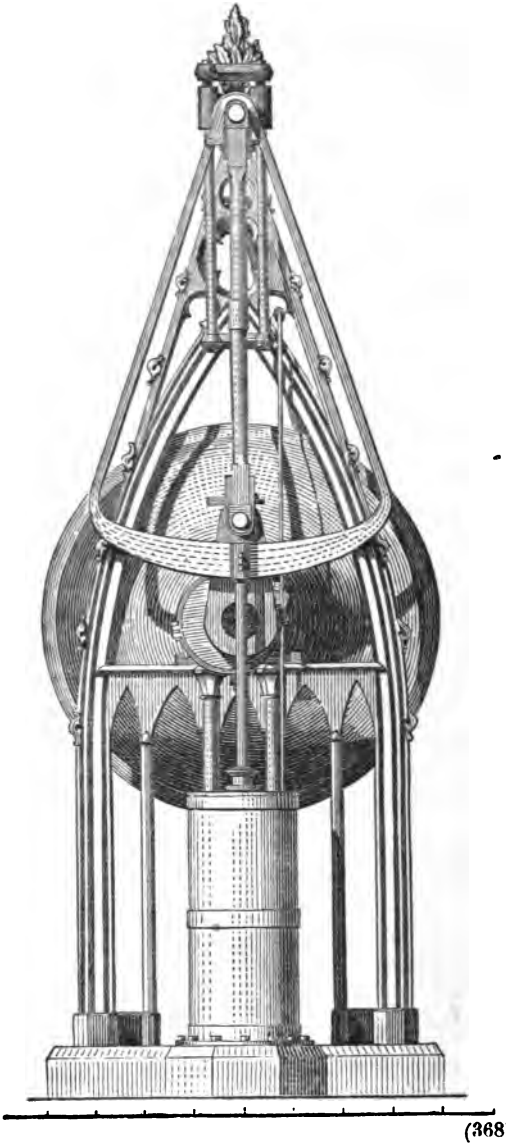
A good stationary expansion engine of 100 horse-power ought not to use more than 4 pounds of coal, or 8 pounds of wood, per hour, per horse-power; a pumping engine, 2 pounds; a marine engine, 10 pounds; a locomotive, 15 pounds; and very small engines, say of two or three horse-power, not more than 20 pounds of coal for the same work Good execution cannot be too highly recommended; an engine well made, built on the same principles as another,

will use but one-half the coal of a carelessly built engine, and one-fourth of that consumed by an ill-executed and ill-kept engine.

EXPANSION, OR CUT-OFF.

If steam is introduced into the cylinder under a certain pressure, and the current of that steam is interrupted before the cylinder is filled, the steam thus confined will press upon the piston, and continue to do so with decreasing tension. If the current of steam of 100 pounds tension is interrupted when the cylinder is half filled, the average pressure in the first half of the cylinder is 100; and when it is expanded to double the volume, that is, when the piston has arrived at the end of the stroke, it will still retain a pressure of 50 pounds. At the end of the stroke of ten times expansion, we find the tension for condensing engines one-tenth, or $\frac{100+15}{10} = 11{\cdot}5$ pounds, of the original pressure of 100 pounds, or 3·5 pounds less than the atmosphere; and the average pressure in the cylinder is $\frac{100+15-3{\cdot}5}{2} = 55{\cdot}7$ pounds. High-pressure engines supplied with 100 pounds pressure can expand the steam but to $\frac{100+15}{15} = 7{\cdot}6$, when the pressure in the cylinder is equal to the atmosphere, and consequently can exert no action upon the piston. The expansion of steam may be carried on until the pressure upon the piston is exhausted; this is seven times on high-pressure engines, with 100 pounds steam; and it may be carried to sixteen times by the same pressure and condensation. If the steam in a boiler is 100 pounds, we never obtain that pressure in the

Fig. 141.



cylinder, but may calculate upon an average of 60 pounds; this will admit of an expansion of $\frac{60 + 15}{15} = 5$ times, to be equal to the atmosphere; and of $\frac{60 + 12}{12} = 6$ times, in case the pressure in the condenser is 3 pounds; and the actual pressure upon the piston will be $6 - 3 = 3$ pounds. In this case we assume that the steam-packing is perfectly tight, which is never the case; and we may conclude that in very good engines the expansion cannot be carried farther than three times by high pressure, and ten times by condensing engines and high-pressure steam. If the cylinder and piston work badly, and the packing leaks, the expansion cannot be carried as far as the above numbers indicate. In many calculations of this kind, a coefficient has been introduced, indicating the necessity of additional heat in expanding steam. It is true that the latent heat of low-pressure steam is greater than that of high density, or tension; but it has been shown in previous pages that the total amount of heat in a pound of low-pressure steam is equal to that in high pressure; the latent heat absorbed by expansion is furnished by the sensible heat, which is reduced to exactly the amount absorbed. We are induced to conclude from this, that one pound of steam, of 100 pounds pressure, does not absorb any more heat than one pound, of three pounds tension. But we are to consider, in this case, that the gases generated by the fuel are the source of heat, and that these gases will always escape with a certain temperature, over and above that of the steam in the boiler, into the chimney. If this temperature is 100° higher than that of the steam, and the temperature of the steam in the boiler is of 3 pounds tension=220°, and that of 100 pounds tension is 330°, the gas in the first instance

will escape with 220 + 100 = 320°, and in the latter with 330+100=430°, a difference of 110°. If the heat generated in the fuel is 3000°, we obtain a useful effect of 3000 — 320=2680° in the first, and of 3000—430=2570° in the latter case, which amounts to a loss of five per cent. in fuel.

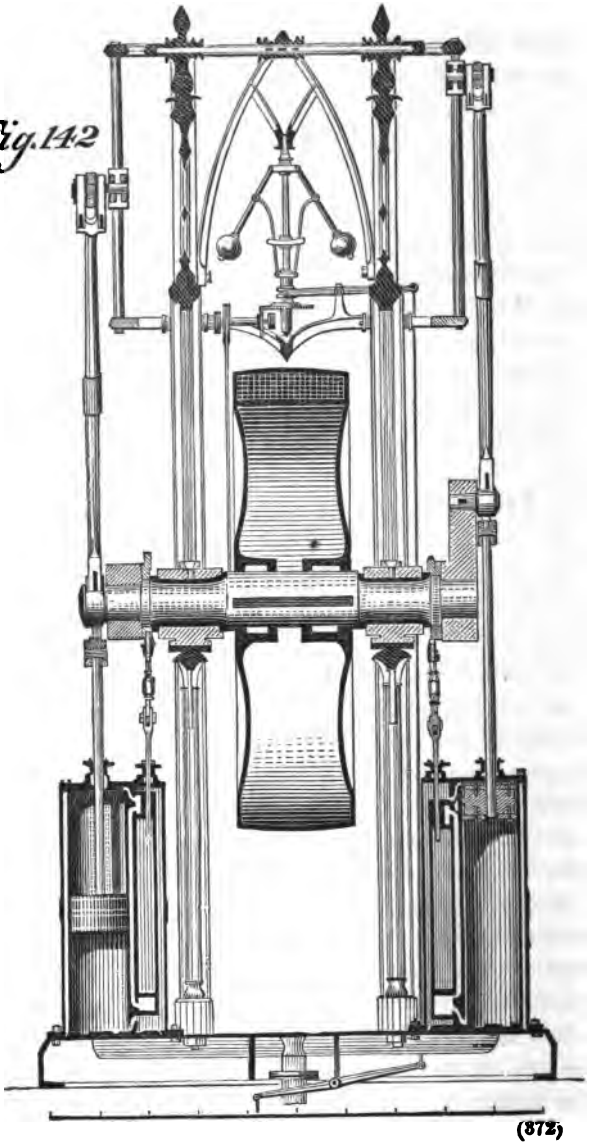
The gain in effect, in the expanded steam, is therefore considerably greater than the loss of fuel under the boiler, in consequence of the higher temperature of the steam. The advantages of moderately dense steam, say of from 20 to 30 pounds, and condensation, are easily explained. If steam of one pressure is expanded to two volumes, we obtain 1·7 effect from it, while its effect, if not expanded, is but one. If expanded three times, its effect is 2·1; if four times, 2·4; five times, 2·6; six times, 2·8; seven times, 3; and ten times, 3·4.

EXECUTED ENGINES.

STATIONARY HIGH-PRESSURE ENGINES.

In concluding our labours, we annex a series of engravings representing steam-engines which are in operation, constructed by I. P. Morris & Co., of Richmond, near Philadelphia — an establishment of extensive reputation for the superior quality of its engines. Fig. 141 represents a side elevation of a high-pressure engine, which is in operation at the United States' Mint, Philadelphia. All the following engravings are true representations, of which the annexed scales furnish one foot in each division. The elevation shows a strong cast-iron frame, in the form of a Gothic ornament. It shows one steam-cylinder, in a vertical position. The piston is connected by its rod with a triangle, which moves vertically up and down with it. At

Fig. 142



(872)

the upper extremity of this triangle, the pin for the connecting-rod is fastened; this moves with the triangle in guides, so as to perform a straight motion with the piston-rod. The connecting-rod extends from here downwards, and, in moving the crank-pin, it performs a pendular motion with the triangle. The crank-pin is always at the same distance from the curved base of the triangle, and in its rotation oscillates from the one side to the other; the crank-pin falls, therefore, within the plane of the triangle. The eccentric for moving the sliding valve is behind the crank, and has but a short distance from the stuffing-box of its rod. The round wheel is a pulley which drives a belt, and, by that means, the machinery annexed to the engine.

Fig. 142 represents a section of the engine. We see here its two steam-cylinders, one on each side of the Gothic frames. Both cylinders are provided with steam-jackets, which entirely surround them, including the steam-chest. The piston-rods are here shown in their relation to the triangles, and also to the connecting-rods and cranks. The spacious sliding valves, which cut off the steam at two-thirds of the stroke, are also represented in section. The steam-pipe leading from the boiler is in the hollow cast-iron platform upon which the engine rests. In the middle, between the two frames, is shown the large pulley in section, as also the main shaft. The governor occupies rather a high position; it is driven by a strap from the main shaft, and regulates, by a long vertical rod, the amount of steam by means of a throttle valve. This engine has no fly-wheel; the rotary motion is equalized by two steam-cylinders, and the cranks are for this reason put at right-angles. No pumps are directly annexed to the engine; the feeding of the boilers is accomplished by a pump independent of

the engine, working by steam drawn directly from the boiler. The engine is calculated to work for 40 horse-powers, and to make 40 revolutions per minute.

This engine has some excellent distinguishing features. The absence of all pumps, and consequent freedom from the vexation arising from their employment, is a very great advantage; and in consequence of this, the engine may be driven with more or less speed, without coming in collision with the speed of the pumps. There is no necessity of working the engine for the sake of pumping water in order to supply the boilers. The absence of the fly-wheel admits of a close and compact arrangement in all the parts of the engine, and obviates the necessity of extensive room. A diminution of friction is another advantage of the removal of the fly-wheel. It cannot be denied that two steam-cylinders are liable to a greater loss in steam than if the same space was obtained in one cylinder; but if the cylinders are well constructed and bored, and the packing close, it is questionable if the loss in power caused by the second cylinder is greater than the loss caused by friction and resistance of air in the fly-wheel. An engine of this construction unquestionably embodies all the elements of a superior machine.

In similar engines, one cylinder may be made to work by a limited expansion; and the other cylinder, receiving the steam from the first, may work its tension to exhaustion, by being larger, and work also by expansion. The application of a continuous expansion, such as that of Samuels', where the steam is conducted into one cylinder and cut off half way, the expansion propelling both pistons, may be of great service. A description of this kind of expansion and its valves may be found in Appleton's Mechanics' Magazine, No. III.

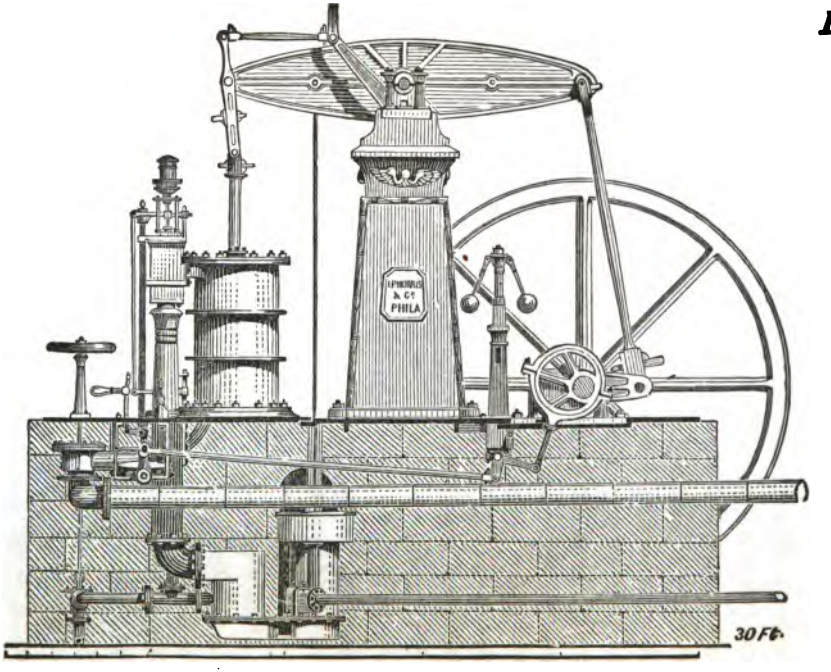


Fig. 143.

STATIONARY CONDENSING ENGINE.

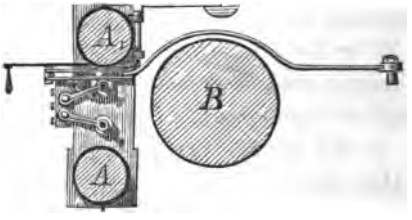
Fig. 143 is a representation of a stationary condensing engine, which is employed in Lancaster, Pa., for driving cotton machinery. This is a beam engine, the beam resting upon a hollow iron pillar. The steam-pipe is conducted below ground, and communicates with two pillars in front of the cylinder; only one of these pillars is here visible. They carry the upper steam-chest in which the poppet valves move, and rest upon the lower steam-chest, which is below the platform of the engine. We shall show the play of these valves in the next engraving. The scale on which the engine is necessarily represented, is too small to show distinctly the mechanism by which the valves are set in motion. The origin of that motion is in the eccentric on the crank-shaft, and it is conducted by quadrants and rods to the steam-chests. The motion of these valves is very easy; they work without the least noise. Below ground we observe the air-pump and condenser, and also the feeding and cold-water pipes.

Engines of this description, working high-pressure steam by expansion and condensation, work very favourably in respect to fuel. A similar engine in the Gloucester cotton-mills, near Philadelphia, drives 16,000 mule and throstle spindles, including all the necessary looms, and spins and weaves No. 28 or No. 30 yarn, by the use of less than five tons of anthracite coal, in twelve hours' actual work, or fourteen hours of engine-work. This brings the consumption of coal to 4·5 pounds per hour, per horse-power — a very favourable exhibit.

MARINE ENGINE.

In fig. 144 we represent a marine engine for paddle-wheels. This engine was used to propel the steam-ship America, of Philadelphia, wrecked on her passage to New Orleans some months since, and may be considered a model of a good engine. A, shows the whole engine in section; we see here the paddle-wheel, crank, connection-rod, and beam in elevation — the steam-cylinder in section, the condensing chamber below it, and the air-pump in its connection with the condenser. The valve-gear is more distinct than in the last engine; we see its motion derived directly from the beam, instead of from an eccentric. The steam-ways are represented in section, and one of the two columns which conduct the steam to and from the cylinder is in view. The other parts of the engine require no explanation; their form and purposes are easily recognized. C shows the crank-gear to the main shafts of the paddle-wheels. B is a front view of the cylinder, and a section of the valves and cut-off; this figure is on twice as large a scale as the others, in order to show more distinctly the parts represented. The steam-pipe is at the top of the

Fig. 145.

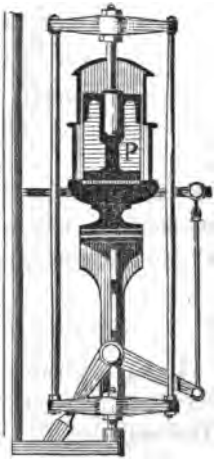


upper steam-chest, which latter we represent in fig. 145, in a view from above, showing the relative position of the

Fig. 14a

steam-cylinder B, and the columns A A; the latter forms the injection-pipe, and the first the exhaust-pipe. In B, fig. 144, we see the water-pipes to and from the condensing chamber, the latter being in view, and also the connection between the condensing chamber and the lower steam-chest. D D are two urns or pots, called Sickel's cut-off; these are connected with the two injection valves, one with the upper, and the other with the lower valve. These pots in which a piston is moving are partly filled with water, upon which the piston plays. The injection valves, on being raised by the valve-gear to a certain height, are suddenly disconnected, and drop, by their own weight and the pressure of steam, quickly into their seats. This sudden motion of the valve would soon break it, were it not prevented by the cut-off, which is more distinctly represented in fig. 146. We see here the piston P in its connection with the lower injection valve. In the exterior pot there is a certain quantity of water, which receives and breaks the blow of the valve, so that the latter settles down quietly, without the least noise. This cut-off is one of the finest improvements on the steam-engine in modern times; it fills a long-needed vacancy in the engine, working with unfailing certainty, and not being liable to injury. The entrance of steam can be regulated in a moment, from the smallest amount, to one-tenth, one-third, or full steam, by the mere shifting of a small lever. On the top of each admission valve is a shifting cam, which may be moved by a lever; this cam

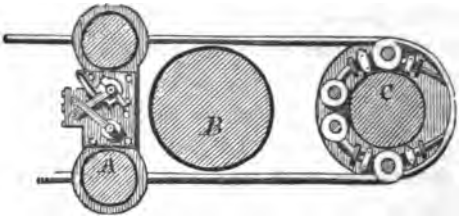
Fig. 146.



decides the time, or how long the valve shall be in connection with the gear which lifted it; in shifting this cam, the valves are sooner or later disconnected, and drop into their seats accordingly.

We see in the engraving that in each valve-seat there are two valves, in order to increase the surface of the steam passage, which may be considered a good arrangement. The valves, as shown, separate the large middle channel or steam-way from the chest, and the steam enters and leaves the cylinder above and below these valves. In fig. 147,

Fig. 147.

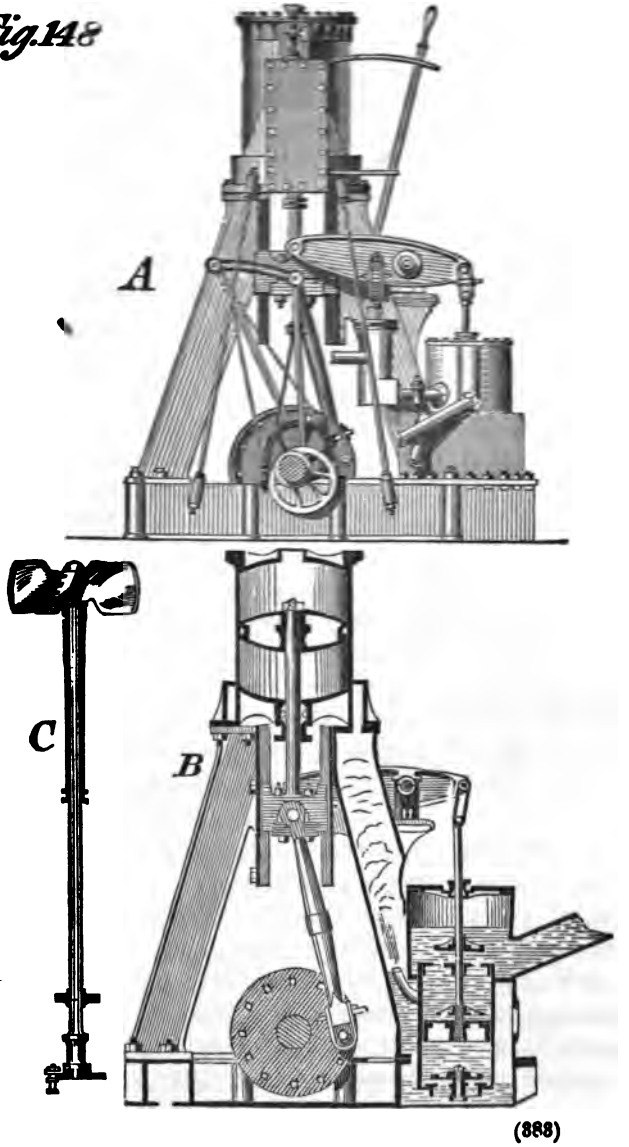


we represent the upper side of the lower steam-chest, and its columns A A, the steam-cylinder B, and the air-pump C; to the latter, two water-pumps are appended.

MARINE ENGINE FOR A SCREW-PROPELLER.

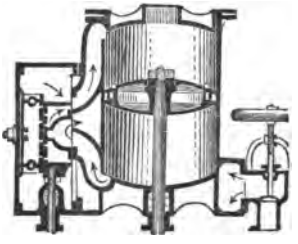
In fig. 148 we represent a steam-engine which propels a screw on the steamer Manuelita Rosas, built in 1851. The cylinder of this engine is 3 feet 2 inches in diameter, and 2 feet 2 inches stroke. The air-pump is 15 inches in diameter, and 15 inches stroke. The screw is 7 feet 6 inches in diameter, and three feet wide, and the blades are inclined at an angle of 48°; its shaft is 9 inches in diameter, and 29 feet long; the eccentric has 6 inches throw.

Fig.148



On each side of the air-pump is a cold-water pump, and the feeding pump is shown in fig. A. The engine imparts from 50 to 55 revolutions to the screw. This engine is remarkable for the small space it occupies, and the compactness and solidity of its parts. The drawing is so comprehensive as not to require any explanation. The cylinder rests on two slanted columns, one of which is hollow, as shown in the vertical section B. This hollow support receives the injection water, and of course the exhausted steam; it serves as a condensing chamber. The piston and piston-rod both have a packing of metal. The valves of the air-pump are stationary, so far as metal is concerned; a sheet of galvanized India-rubber forms the movable parts of the valves.

Fig. 149.



In fig. 149, the cylinder and sliding valves, as well as the steam-valve, are represented. The sliding valve and steam-ways are very large, and the friction of the first is diminished by a steam-box, which fits to the back of the sliding valve, and prevents the steam from pressing upon it. In the side of this box, where it joins the valve, there are various passages for steam, which alternately shut and open with the motion of the valve, and in that way increase the passage for steam. The sliding valve forms two such passages with the box for each steam-way. In fig. 148, C is a representation of the shaft and screw, with its long stuffing-box, passing through the stern of the vessel. In fig. 150, the screw, with the arrangement of its blades, is shown; of which A is half a section across the blades, and

B a view of the four blades, which are screwed to a cast-iron centre, and are also made of cast-iron. Fig. 151

Fig. 151.

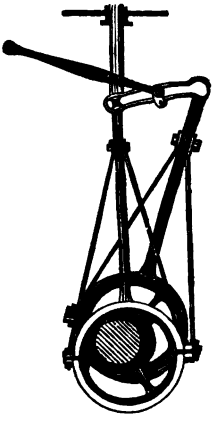
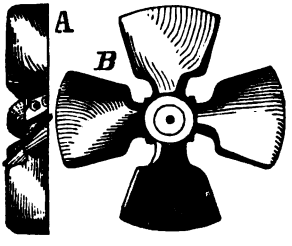


Fig. 150.



shows the arrangement of the valve-gear; the motion of the sliding valve is changed, and a backing of the vessel produced by throwing either one or other of the eccentrics into gear.

We regret that the limits of this book do not admit of our adding some further illustrations of steam-engines and other machinery, particularly some of the horizontal engines which are in such general use in the Western States. In principle, there are some serious objections to horizontal engines; still, there are large engines of this kind in operation, which compare favourably with some of our best vertical engines. Small engines, which are to make many revolutions, are in most cases of more useful effect if driven by a horizontal cylinder. Engines for driving saw-mills or hammers, or in fact any machinery which can be driven by the engine directly, are in most cases horizontal.

SUSPENSION BRIDGES.

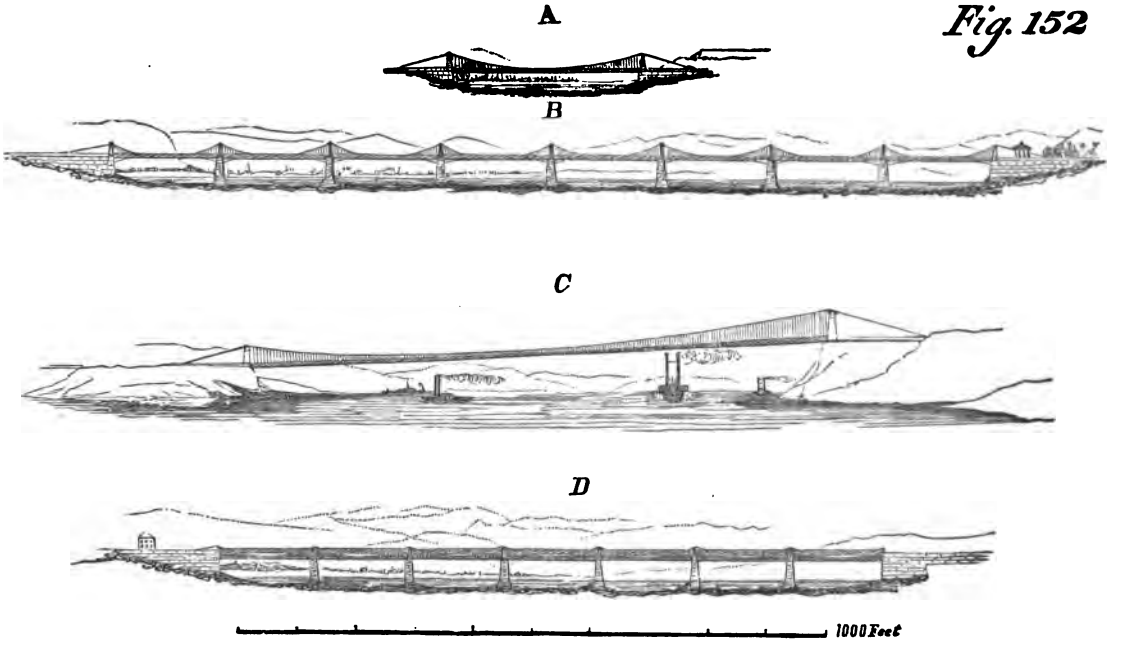
In conclusion, we annex a plate representing some of our best suspension bridges. We feel no inclination to furnish a treatise on bridge-building; we merely wish to draw the attention of the community to this kind of bridges, as the most suitable for our purposes. We do so because we observe a want of confidence in the efficacy of these bridges. The rapid progress of population in our land requires an unprecedented extension of roads, and, as a consequence, of bridges. The erection of the latter is always attended with heavy expenses; and as the number, and in many cases the length, of these structures, is very great, it is an object of national interest to arrive at a safe, and at the same time economical way of crossing rivers. The means which have been employed by the ancients, namely, arched stone bridges, however durable they may be, are impracticable in the majority of cases with us, partly on account of expenses, but chiefly because stone bridges require a large number of piers, which obstruct navigation. Wooden bridges are therefore preferable, and most of our bridges are built of that material. Wood is certainly well adapted to the formation of such constructions, if protected against the influence of the atmosphere; but they are expensive in the course of time, from their liability to destruction by fire and flood. Another objection to wooden bridges is that which we have referred to as characterizing the viaducts of the ancients — the expensive piers requisite for their support, and the consequent obstruction to navigation. Recently, iron truss bridges have made their appearance, and great ingenuity and skill has been bestowed upon their construction; they appear to be well qualified for short spans, but are doubtful and dangerous in long distances;

they do not afford the security so essential in a bridge The most recent improvement in bridges is the construction of compound beams, which has found a very extensive application in the Conway bridge in England. This bridge is to all appearance safe for a span of 400 feet, which may be considered a sufficient distance for navigable rivers. But, admitting that this bridge is superior to all others, it is too expensive for our purposes. Where, in England, or any European State, they are under the necessity of building one bridge, we have to construct ten or more; further, we have to span rivers of a magnitude of which Europeans have no conception; and therefore structures which may be most suitable to other nations, are impracticable among us. Besides, we want bridges which may pay an interest on the capital invested in their construction; we have no ambition of erecting national monuments over every stream. We require cheap and durable bridges, in order to multiply their number, and facilitate their erection.

The wire suspension bridge unites all the qualities requisite in a good, durable, and safe bridge. There is no form of bridge which affords so much security and safety as this bridge; no other structure can be calculated with so much nicety as to its capacity for burden; no other form of bridge requires less knowledge to calculate its elements; and, notwithstanding its oscillations and seeming weakness, it is unquestionably stronger than any description of bridge with which we are acquainted. So far as the carrying of a burden is concerned, nothing can be conceived superior to it.

At first sight, the theoretical elements of a wire suspension bridge appear to be complicated; but in reality this is not so. We can depend upon the tenacity of iron wire with certainty; but not so in respect to other forms of iron.

Fig. 152



The strain of the loaded bridge on the wire is easily calculated; and if we multiply that strain by 3, 4, or 6, we obtain a sufficient, infallible strength for the cables. The pressure of the whole bridge upon the towers and abutments, or piers, is easily found; and if we make the material for these piers and towers ten or twenty times as strong, there is no danger of crushing it. The anchorage of the chains in the abutments is equally as safely calculated as the size of the cables and towers, by taking the strain at the cables, and loading the anchorage with sufficient material to resist that strain.

A serious objection to these bridges is the oscillation to which they are generally subject, and which has hitherto prevented their application as rail-road bridges. This objection is so much the more serious, as the oscillations tend to weaken the structure, and bring it to premature decay, at least so far as the wood-work of the bridge is concerned. To meet this objection, and to show a method of avoiding these oscillations, is the object of this allusion to suspension bridges.

In fig. 152, we give a representation of some of our suspension bridges, with their relative sizes. A, represents the wire bridge over the Schuylkill river at Fairmount, near Philadelphia; B, that over the Monongahela river, at Pittsburgh; C, the Wheeling suspension bridge across the Ohio river; and D, the suspension aqueduct across the Alleghany river at Pittsburgh, conducting the water of the Pennsylvania canal into the city. The annexed scale shows the length of these various structures.

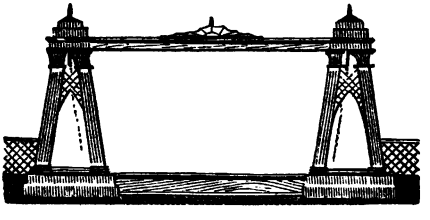
We wish to draw particular attention to the aqueduct D; it was erected by John A. Roebling, now of Trenton, N. J., in the years 1844–5, and was opened in May, 1845, for navigation. This bridge is 1140 feet long, and consists of

seven spans. This limited length of span was owing to the fact that a number of piers were standing, having been erected to support a wooden structure, which had been taken down in order to be replaced by the suspension aqueduct. There is no necessity of alluding to the particulars of this bridge; it is generally and favourably known, and its superior merits acknowledged. What we wish, is to draw attention to its solidity, and freedom from oscillation or vibratory motion. The rigidity of the structure is so great, that one span might be destroyed without affecting in the least any of the other spans. This bridge is qualified to carry a heavy load of water, and often two or three boat-loads of 100 tons weight, upon one span more than upon another, without causing undulations. A similar structure may therefore serve as a rail-road bridge, as the cars of a heavy train will not cause as much depression as these heavily-loaded canal-boats; and if it resists the influence of the latter so effectually, it will certainly resist a locomotive and train of cars. The plan of this work presents a series of advantages, which cannot be too highly appreciated; it combines great strength, stiffness, safety, durability and economy; even a wooden bridge cannot be built for less money.

The second illustration in our plate to which we wish to draw attention is the bridge over the Monongahela river, B, built by the same engineer, Mr. Roebling. This bridge was built to supply the place of a wooden structure destroyed by the great fire which consumed nearly half of the city of Pittsburgh, in 1845. This bridge is 1500 feet long, divided into eight spans of 188 feet each. The two wire cables, one on each side of the bridge, are $1\frac{1}{2}$ inches in diameter, and each contains 750 wires, forming a round compact body, protected by a close wrapping of wire; each

wire being repeatedly coated with linseed oil, and the whole covered with red lead. The weight of the superstructure of one span is 70 tons, which is to be supported by the cables and towers. The tension of this weight on the cables, when the bridge is at rest, is 122 tons; and when four teams of six horses each are on one span, these increase the vertical weight by 28 tons, increasing the strain on the cables 49 tons. One hundred head of cattle would increase the vertical weight about 40 tons, which amounts to 70 tons in the cables. The aggregate weight of a span with 100 head of cattle on it would be 110 tons, and this produces a tension in the cables of 192 tons. The ultimate strength of both cables is 860 tons. We see here that the cables are 4·5 times as strong as is requisite for the support of the heavily laden bridge, and that there is no danger of their ever giving way; no rupture of the iron under that load is possible. The width of the bridge is thirty-two feet between the railings on each side, and the cables separate the roadway from the sidewalks. These pass through the cast-iron towers, as shown in fig. 153. These towers

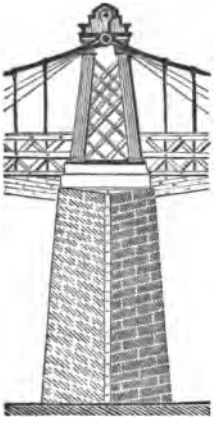
Fig. 153.



are braced by a beam, in order to resist the side tension of the cables more successfully than would otherwise be possible. The sidewalks are elevated some six or eight inches

above the roadway, in order to keep the wood dry on both. The cables are suspended in the towers on vertical chain-links or pendulums, which serve to throw the pressure of the cables, and consequently that of the bridge, in the axis of the towers. This arrangement is peculiar to the bridge under consideration, and is shown in fig. 154; it serves to prevent jarring and side strain upon the towers, and is indeed a most successful means for that purpose, if the results shown by this bridge are attributable to the suspension of the cables in this manner. It must appear clear to every mind, that but little of the motion of the roadway can be imparted to the towers. At both ends of the bridge, the wire cables are replaced by anchor chains of solid flat iron, which reach from the end towers to the anchorage below ground. The wires are here replaced by solid iron, in order to bring solid, compact iron in the reach of oxidation, as it will resist its destructive influence more successfully than wire.

Fig. 154.



This bridge is remarkable for its stiffness; one or more six-horse coal-wagons hardly affect it, or cause any shaking or oscillation; at least these are not more perceptible than on a strong wooden bridge. This is so much the more remarkable, as the bridge is light, and, by reason of the number and shortness of the span, is more liable to vibrations than a bridge composed of long spans. It is in all cases more difficult to prevent oscillation in a light and short bridge, particularly if of many spans, than it is in a long and heavy bridge. This object has been accomplished,

partly by means of the above-mentioned pendulums, but chiefly by means of stays, or iron rods, which radiate from the point of suspension at the pendulum, towards the deflection of the cables. Besides these stays, the roadway is strengthened by a timber support at each abutment, and at each pier. This bridge shows such evidence of progress in the art, that it must lead to the general adoption of suspension bridges.

From the success attending the erection of these bridges, there seems to be not the slightest doubt of the capability of a suspension bridge to carry a train of cars. There is nothing equal in safety to a wire bridge in carrying almost any load we choose; and there is not the remotest cause of danger in such structures, if they are well calculated, sufficient strength given, and the plans laid faithfully carried out. The only thing in which these bridges generally are found deficient, is stiffness; and we are well aware of the difficulties arising from this fault, and also of the ineffectual attempts to correct this defect by mere alterations of the curve in the cables, and by similar means. Wood and iron, either cast or wrought, are sufficient to impart any degree of stiffness to a bridge, if judiciously applied. If we can suspend a roadway with such stiffness as to prevent local depression, and distribute that depression over the whole bridge, or the longest part of it, thus preventing short-timed vibrations, we shall have a bridge superior, as regards safety, durability and utility, to anything in the whole range of bridge-building. Such a result can unquestionably be attained; there are abundant means within the reach of constructors, by which the object may be accomplished. It is not our intention to offer any advice on the subject; indeed, it is yet in some measure an open field for

the exercise of the talents of those who engage in the erection of these structures; but we hope the hints we have thrown out may be of some assistance in guiding contractors into whose hands this volume may fall. If so, our aim will be accomplished, and we shall feel sufficiently rewarded for our exertions.

APPENDIX.

TABLES OF FRICTION.

TABLE I. — *Friction between two Surfaces which have been at rest for some time.*

Kind of material.	Direction of the fibres.	Condition of the surfaces.	Coefficient of friction.
Oak upon oak	parallel	without lubrication	·62
do.	"	dry soap between	·44
do.	at right angles	without anything	·54
do.	"	moistened by water	·71
do.	face on fibres	clean	·43
All other wood on oak	parallel	"	·53
Oak on leather	flat	"	·61
do.	face, or edge	moistened	·79
do.	"	dry	·43
Hemp rope on oak	parallel	moistened	·87
do.	"	dry	·80
Iron on oak	"	moistened	·65
Cast-iron on oak	"	"	·65
Brass on oak	"	dry	·62
Leather on cast-iron	flat	moistened	·62
do. do.	edge	oil, soap, or grease	·12
do. on cast-i'n wh'ls	flat	dry	·28
do. do. do.	"	moistened	·38
Cast-iron on cast-iron	"	dry	·16
Wrought-iron on do.	"	"	·19
Sandstone on s'dstone	"	"	·74
Limestone on do.	"	"	·75
Brick on do.	"	"	·67
Oak on do.	"	"	·63
Iron do.	"	"	·49
Limestone on limestone	"	"	·70
Brick on do.	"	"	·67
Iron on do.	"	"	·42
Oak on do.	"	"	·64

In referring to this table, we have to remember that very slight vibrations are sufficient to render it useless; for such vibrations will

almost always loosen the surfaces, and the conditions under which this table was compounded will be altered. When such is the case, the other tables of friction are used.

TABLE II. — *Table of Friction for Plane Surfaces when in motion.*

Kind of material.	Direction of the fibres.	Condition of the surfaces.	Coefficient.
Oak on oak	parallel	dry	·48
do.	"	dry soap	·16
do.	crossing at r't ang.	dry	·34
do.	"	moistened	·25
do.	face on fibres	dry	·19
All other wood on oak	crossing at r't ang.	"	·36 to ·40
Wrought-iron on oak	parallel	moistened	·26
do.	"	dry soap	·21
Cast-iron on oak	"	dry	·49
do.	"	moistened	·22
do.	"	dry soap	·19
Brass on oak	"	dry	·62
Leather on oak	"	"	·27
do.	"	moistened	·29
Leather on cast-iron, bronze	"	dry	·56
do.	"	moistened	·36
do.	"	greased	·23
do.	"	oiled	·15
Hemp rope on do. do.	"	dry	·52
do.	"	moistened	·33
Wr't-iron on wr't-iron	"	dry (abraded)	·44
Wrought-iron on cast-iron and bronze	"	dry	·18
Cast-iron on cast-iron	"	"	·15
Bronze on bronze	"	"	·20
Bronze on cast-iron	"	"	·22
Bronze on wr't-iron	"	"	·16
Sandstone on s'ndstone	"	"	·64
Limestone on do.	"	"	·67
Brick on do.	"	"	·65
Oak on do.	"	"	·38
Wrought-iron on do.	"	"	·38
Limestone on limestone	"	"	·69
Oak on do.	"	"	·38
Wr't-iron on do.	"	"	·24
do.	"	moistened	·30

TABLE III.—*Table of Friction for Journals moving in their Pans.*

Material.	Condition of surfaces.	COEFFICIENT. Lubricated at intervals.	Lubricated perm'ntly.
Journals of cast-iron in pans of cast-iron	Oiled or greased, and grease with plumbago	·07 to ·08	·05
	The same lubrication, but water to it	·08	"
	lubricated by asphaltum	·05	"
	not lubricated	·14	"
	not lubricated, wet	·14	"
Journals of cast-iron on pans of bronze	oil, grease, or plumbago	·07 to ·08	"
	dry	·16	"
	moistened	·16	"
	quite dry	·19	"
Journal of wrought-iron on a pan of cast-iron	oil, grease, or plumbago	·07 to ·08	"
Journal of wr't-iron on a pan of bronze	oiled or greased	·07 to ·08	"
	wagon grease	·09	"
	grease and water	·19	"
	dry	·25	"
Journals of bronze in bronze	oiled	·10	"
	greased	·09	"
do. bronze in cast-iron	oiled or greased		·04 to ·05

The tables on friction are applied by multiplying the pressure or weight of the bodies which slide upon one another, by the coefficient of friction; the result is the loss in power caused by friction.

TABLE IV.—*Velocities of Water from Apertures, calculated for certain heights.*

Height in feet.	Velocity in feet.	Height in feet.	Velocity in feet.
¼	4·0	7	21·1
½	5·6	8	22·6
¾	6·9	9	24·
1	8·	10	25·3
1½	9·8	11	26·5
2	11·3	12	27·7
2½	12·6	13	28·8
3	13·8	14	29·9
4	15·9	15	30·6
5	17·9	16	31·6
6	19·6		

TABLE IV., *showing the Coefficients for the Efflux through rectangular Orifices in a thin vertical Plate.*

The heads of water were measured at a certain distance back from the orifice, where there was no turbulence.

Head of water to the upper edge of the orifice, in inches.	SIZE OF THE ORIFICE.	
	Eight inches square.	Four inches square.
·78	·57	·59
1·18	·57	·6
1·57	·58	·6
2·36	·58	·6
3·14	·58	·61
4·72	·59	·61
5·51	·59	·61
6·29	·59	·61
7·08	·59	·61
7·87	·59	·61
9·84	·59	·61
11·81	·6	·61
15·75	·6	·61
19·68	·6	·61
23·62	·6	·61
27·56	·6	·61
31·49	·6	·61
35·43	·6	·61
39·37	·6	·61
43·30	·6	·61
47·24	·6	·61
51·18	·6	·61
55·11	·6	·61
59·05	·6	·61
62·99	·6	·61
70·86	·6	·6

TABLE VI.—*Mean Velocity of Water in Canals.*

Velocity on the surface per sec'd in feet.	Coefficient for multiply'g surface veloc'y.	Velocity on the surface per sec'd in feet.	Coefficient for multiply'g surface veloc'y.
1·64	·786	9·84	·873
3·28	·812	11·48	·883
4·92	·832	13·12	·891
6·56	·848	14·76	·898
8·20	·862	16·40	·904

TABLE VII.—*Quantity of Water furnished by a Pump, for one man's labour, in one minute; the lever being* 1 to 5.

Height of pump in feet.	Diameter of bore in inches.	Quantity of water in gallons.	Height of pump in feet.	Diameter of bore in inches.	Quantity of water in gallons.
10	6·93		60	2·84	13
15	5·66	81	65	2·72	12
20	4·90	54	70	2·62	11
25	4·38	40	75	2·53	10·7
30	4	32	80	2·45	10·2
35	3·70	27	85	2·38	9·5
40	3·46	20	90	2·31	9·1
45	3·27	18	95	2·25	8·5
50	3·10	16	100	2·19	8·1
55	2·95	14			

The results in the last column may be reduced one-half; for they are by far too high.

TABLE VIII.—*Height to which Water will rise in the Air, on being discharged through a small aperture, as in fountains.*

Head of water in feet - - -	37·7	37·2	27·8	26·0	13·1	5·8
Height of fountain in feet - -	34·0	33·7	25·8	24·3	12·7	5·5

TABLE IX.—*Evaporation of Water at different Pressures, from a surface of six square inches, in half an hour's time.*

Pressure with mercury.	Grains.	Pressure with mercury.	Grains.
30·4	1·24	1·9	15·92
15·2	2·97	·95	29·33
7·6	5·68	·47	50·74
3·8	9·12	·07	112·22

TABLE X.—*Force of Vapour and Rate of Evaporation per minute from a surface of twenty-eight square inches.*

Temperature.	Force. Inches mercury.	Calm. Grains.	Breeze. Grains.	High winds. Grains.
212°	30	120	154	189
85	1.235	4·92	6.49	8.04
75	·906	3·65	4·68	5·72
65	·657	2·62	3·37	4·12
55	·476	1·90	2·43	2·98
45	·340	1·36	1·75	2·13
35	·240	·95	1·22	1·49
25	·170	·67	·86	1·05

TABLE XI.—*Weight of a cubic foot of Steam at different temperatures.*

32 degrees	2·53 grains	70 degrees	8·39 grains
40 "	3·23 "	80 "	11·33 "
50 "	4·53 "	90 "	15 "
60 "	6·22 "	212 "	257·218 "

TABLE XII.—*Degree of Heat for different densities of Steam, generated from sea-water and from pure water.*

Common water. Boiling point.	Elastic force.	Sea-water. Boiling point.	Elastic force.
212°	30 inches.	212°	23 inches.
216°	32 "	216°	24 "
220°	35 "	220°	26 "

TABLE XIII.—*Temperatures and corresponding Densities of Steam.*

Temperature in degrees.	Pounds of pressure.	Inches of mercury.	Volume of steam compar'd with one volume of water.
212°	14·7	30	1711
228	20	40·8	1281
241	25	51	1044
251	30	61·2	883
260	35	71·4	767
269	40	81·6	679
276	45	91·8	610
283	50	102	554

TABLE XIV.—*Force and Temperature of Steam.*

1 atmosphere	212 degrees.	14 atmospheres	386·94
2 "	250·52 "	15 "	392·86
3 "	275·18 "	16 "	398·48
4 "	293·72 "	17 "	403·82
5 "	307·5 "	18 "	408·92
6 "	320·36 "	19 "	413·78
7 "	331·70 "	20 "	418·46
8 "	341·78 "	21 "	422·96
9 "	350·78 "	22 "	427·28
10 "	358·88 "	23 "	431·42
11 "	366·85 "	24 "	435·56
12 "	374 "	25 "	439·34
13 "	380·66 "	50 "	510·60

TABLE XV.—*Boiling Points of Liquids.*

Ether	100°	Water	212°
Sulphuret of carbon	113	Oil of turpentine	316
Alcohol, spec. grav. ·813,	173.5	Sulphuric acid	600
Nitric acid	210	Mercury	655

TABLE XVI.—*Weight of Water at common temperatures.*

1 cubic inch	= ·03617	pounds.
1 " foot	= 62·5	"
1 " "	= 6·25	imp. galls.
1 cylinder inch	= ·02842	pounds.
1 " foot	= 49·1	"

TABLE XVII.—*Weight and Measure of Water in an inch pipe.*

Height in feet.	Contents in cubic inches.	Weight in oz., avoirdupois.
1	9·42	5·46
2	18·85	10·92
3	28·27	16·38
4	37·17	21·85
5	47·12	37·31
6	56·55	32·77
7	65·97	38·23
8	75·40	43·69
9	84·82	49·16
10	94·25	54·62

The amount of water in a pipe of any size is found by multiplying the length of it by one of the measures in the columns, and the square of the diameter of the pipe in inches. The contents are then cubic inches and ounces.

TABLE XVIII.—*Latent Heat of Vapours.*

Water at 212°	1000°
Alcohol	457
Ether	312·9
Oil of turpentine	183·8
Nitric acid	550
Ammonia	865·9
Vinegar	903

TABLE XIX.—*Boiling Points of various Liquids, by a 30-inch Barometer.*

Ether	87·4
Alcohol	175·4
Turpentine	523·4

Linseed oil	600·8
Sulphur	570
Sulphuric acid	590
Mercury	660

The results shown for ether, alcohol, turpentine, and linseed oil, are more correct than those given in the previous table.

TABLE XX.—*Velocity of Wind.*

	Feet per second.	Pressure per sq. foot, in pounds.
Scarcely sensible	1·5	·005
Gentle wind	3	·123
Moderate breeze	6	·133
Brisk breeze	18	1·21
Good breeze	22	2·85
Brisk gale	30	4·42
High wind	45	9·96
Very high wind	60	17·71
Storm	70 to 90	30·49
Hurricane	100 or more.	

TABLE XXI.—*Tension and Velocity of Air in a Blast Machine.*

Height of mercury at the manometer, in inches.	Pressure upon one square inch.	Real velocity per second, in feet.
1	·549	149
2	1·099	211
3	1·648	262
4	2·198	304
5	2·747	344
6	3·297	380
7	3·846	412
8	4·396	442
9	4·945	471
10	5·495	499
11	6·044	527
12	6·584	554
13	7·143	580
14	7·693	605
15	8·242	629

The velocities are calculated for a nozzle of 12° slope.

TABLE XXII.—*Liquefaction of Gases.*

	Pressure in atmospheres.	Temperature.
Sulphurous acid	2	45°
Cyanogen	4	60
Ammonia	6½	50
Sulphuretted hydrogen	17	50
Carbonic acid	36	32

TABLE XXIII.—*Specific Heat of various Substances.*

Water	1·0000	Glass	·1770
Mercury	·0330	Alcohol	·0700
Silver	·0557	Ether	·0600
Zinc	·0927	Air	·2669
Copper	·0940	Hydrogen	3·2936
Iron	·1098	Carbonic acid	·2210
Bismuth	·0288	Oxygen	·2361
Lead	·0293	Nitrogen	·2754
Gold	·0298	Steam	·8470
Tin	·0514		

TABLE XXIV.—*Fusibility of various Substances.*

Bismuth									459°
Lead									540
Tin									403
Sulphur									236
Pitch									186
White wax									155
Yellow "									140
Tallow, ship									124
" common									92
Phosphorus									110
Butter									86
Tin	3	parts,	lead	5	parts,	bismuth	8	parts,	melts by 212
"	3	"	"	2	"	"	5	"	212
"	2	"	"	3	"	"	5	"	197
"	3	"	"	3	"	"	8	"	202
"	3	"	"	6	"	"	8	"	208
"	3	"	"	8	"	"	8	"	226
"	4	"	"	8	"	"	8	"	236
"	6	"	"	1	"	"	5	"	245
"	4	"	"	8	"	"	8	"	243
"	8	"	"	8	"	"	8	"	254
"	8	"	"	10	"	"	8	"	266
"	8	"	"	12	"	"	8	"	270
"	1	"	"	—	"	"	1	"	286
"	3	"	"	2	"	"	—	"	333
"	8	"	"	—	"	"	1	"	392

A cherry-red heat on iron, in the dark, is	750°
" " " in daylight	884
" " " in fire	1050

TABLE XXV.—*Linear Extension by Heat of a Rod which is* 1 *at* 32°; *calculated for* 212°, *or boiling heat.*

Glass tube	1·00083333
Plate glass	1·00089089
Platina	1·00085655
Antimony	1·00108300
Cast-iron	1·00110940
Steel	1·00118990
" not tempered	1·00107875
" hardened	1·00122500
Wrought-iron	1·00115600
" soft	1·00122045
" wire	1·00144010
Copper	1·00191000
Brass	1·00185540
" wire	1·00193000
Bronze	1·00181700
Silver	1·00189000
Speculum metal	1·00193300
Hard solder	1·00258000
Tin	1·00193760
Pewter	1·00228300
Grain tin	1·00248300
Soft solder	1·00250800
Zinc	1·00294200
" hammered	1·00301100

The expansion of liquids, on being heated from 32° to 212°, is as follows:

Mercury	·0180180	Alcohol	·1100
Water, from 27°	·04332	Brine, or water saturated by common salt	·0500
Muriatic acid	·06000		
Nitric acid	·1100	Fixed oil	·0800
Sulphuric acid	·0600	Oil of turpentine	·0700

All gases, steam included, expand for each degree $\frac{1}{180}$.

TABLE XXVI.—*Specific Heat of Iron at various Temperatures.*

From 32° to 212°	·1098
" 32 to 392	·1150
" 32 to 572	·1218
" 32 to 662	·1255

TABLE XXVII.—*Specific Gravities of Matter.*

Mercury	13·598	Gneiss	2·39 to 2·71
Lead	11·33	Limestone	2·40 to 2·86
Copper	8·75	Sandstone	1·90 to 2·70
Cast-iron, white	7·5	Brick	1·40 to 2·22
" grey	7·1	Masonry, fresh	2·46
Bar-iron	7·6	" dry	2·40
Brass	8·55	" brick	1·50 to 1·70
Zinc, cast	7·00	Stamped earth, fresh	2·06
" rolled	7·5	" dry	1·34
Granite	2·50 to 3·00		

TABLE XXVIII.—*Absolute Cohesion of Wrought-iron, according to Telford's and Brown's Experiments.*

Kind of Iron.	SIZE OF IRON.				By what weight torn asunder.
	Before stretching.		After stretching.		
	Length.	Thickness.	Length.	Thickness	
	Ft. in.	Inches.	Ft. in.	Inches.	Tons. lbs.
Welsh iron, round	2·2 3/4	1 1/8	2·6 7/8	1 1/8	43·1232
Staffordshire, square	1·5 1/8	3/4	1·11 1/4	6/16	15·648*
" "	1·7 1/4	1 1/2	1·9 1/4	5/8	32 676*
Welsh iron, square	—	1	—	—	29
Swedish, "	—	1	—	—	29
Scrap iron, "	—	1	—	—	29
Staffordshire, "	—	1	—	—	31
Common, unk'n, round	2	2	2·2 7/8	1 1/2	100
Swedish, square,	3·6	1 5/16	3·6 3/16	1 1/16	40·2128
" "	3·6	"	—	1 1/16	39·1680
" "	3·6	1 3/16	3·9	7/8	33·1120
Russian, "	3·6	1 5/16	3·8 1/2	1	36·224
Welsh, "	3·6	1 1/4	3·8	1 1/16	38·112
" "	3·6	1 1/8	—	1 1/16	31
" "	12·6	2	14·5	1 1/8	82
" "	5	1 3/8	5·7	—	43 1/2

The stretching of most of these bars commenced at three-fifths of the weight, and continued until the bar broke. When the stretching was not carried too far, the rod would in many instances return after releasing the force. At the moment of breaking, a scorching heat was liberated at the torn end. The results marked thus * were obtained with the same kind of iron.

One square inch of English charcoal iron will carry, before being torn asunder .....pounds 55,698
One square inch of Swedish charcoal iron 71,473
" hard drawn wire, No. 12, Swedish iron, 130,000
" " " best Penn'a, 130,000
" " " common " 70,000
" soft drawn wire, " Swedish, 80,000
" " " best Penn'a, 75,000
Good charcoal iron, carefully worked, may carry 1 in. sq. rod, 58,000
The same iron, " " ½ " 75,000
" " " ¼ " 90,000
" " " less sq. " 100,000
" " " fine wire, 130,000
Common shear-steel, from the forge-hammer 108,000
Refined " " 124,000
Good cast-steel, hardened, but not tempered 112,000
" " yellow temper 150,000
" " blue temper.....135,000

Steel stretches very little (scarcely anything) before it breaks; it also heats but little in being broken.

Grey cast-iron may bear to the square inch..... pounds 20,000
" " " " 15,680
" " " " if the best charc'l, 60,000
White " " " " 18,000

We cannot depend upon an average of more than 18,000 pounds in coke iron, 22,000 for anthracite cast-iron, and from 20 to 60,000 pounds for charcoal cast-iron, if they are all grey; white iron carries considerably less, the more it is inclined to that state.

TABLE XXIX. — *Table of Absolute Cohesion or Tenacity.*

One square inch will carry to the point of rupture, in pounds, as follows:

Ash wood	14,130	Pine wood, white	12,000
Beech	12,225	" red	11,800
Brass	17,968	Gun-metal	35,838
Brick	275	Lead	1,824
Cast-iron	13,434	Mahogany	11,475
Copper	33,000	Hemp rope, 1 in. in circum	200

Hemp rope, sq. in. Germ'n,	10,800	Wood, poplar	7,200
" " English,	5,400	Cast-iron	13,505 to 17,136
" " "	19,000	" best	28,000
Tin	4,736	Wrought-iron	65,520
Zinc	9,120	Iron wire, hard,	65,000 to 128,000
Fine-grained sandstone	215	" annealed	half
Brick	275	Sheet-iron	52,000
Glass	3,565	Brass wire, hard	98,960
Hydraulic mortar	168	" annealed	49,000
Common mortar	43	Gun-metal, hard	36,368
Wood, beech	17,850	Copper, rolled	35,000
" oak	9,198	" cast	19,200
" mahogany	16,500		

Hemp ropes, English, 6 tons per pound's weight, per foot long.
Wire ropes, English, 12 tons per pound's weight, per foot long.
" American, (Trenton, N. J.) 18 tons per pound and per foot long.

TABLE XXX.—*Strength of Rope, Wire Rope, and Chains.*

ROPE.		CHAIN.		SOLID WIRE ROPE.		Strength.
Circumference.	Weight per yard.	Diameter of iron.	Weight per yard.	Diameter of wire 1-12 in.	Weight per yard.	
Inches.	Lbs.	Inches.	Lbs.	No. of wires.	Lbs.	Tons. Cwt.
3·50	1⅜	5/16	2¾	10	½	1·05
4·25	2⅛	⅜	4	18	1	1·16
5	2⅞	7/16	5½	19	1 1/2	2·10
5·75	3½	½	7	22	1⅝	3·05½
6·50	4⅛	9/16	9	26	1½	4·03½
7	5⅛	⅝	11	33	1¾	5·02
8	7½	11/16	13½	42	2½	6·04½
8·75	9½	¾	16	50	3	7·07
9·50	10½	13/16	18½	58	3½	8·13½
10	11½	⅞	21½	66	3¾	10
10·75	14	15/16	24½	77	4⅛	11·11
11·50	15½	1	28	90	5	13·08
12·25	18	1 1/16	31½	103	5⅝	14·18
13	19½	1⅛	35½	114	6⅛	16·14
13·75	22½	1 3/16	38½	126	7	18·11
14·50	24¼	1¼	43½	140	7⅝	20·08
15·25	28	1 5/16	48	154	8½	22·13
16	30	1⅜	53	170	9½	24·18

TABLE XXXI.—*In which Iron Cables are computed as equal to those of Hemp.*

IRON CABLES. Diam. of rods in inches.	HEMP CABLES. Circumference of rope.	Resistance to breaking, in tons.
$\frac{7}{8}$	9	12
1	10	18
$1\frac{1}{8}$	11	26
$1\frac{1}{4}$	12	32
$1\frac{5}{16}$	13	35
$1\frac{3}{8}$	$14\frac{1}{2}$	38
$1\frac{1}{2}$	16	44
$1\frac{5}{8}$	17	52
$1\frac{3}{4}$	18	60
$1\frac{7}{8}$	20	70
2	23	80

The comparisons between hemp and iron are only relatively true, and apply but to particular cases. The quality of hemp and iron is of great variety, and it is impossible to lay down rules which shall be applicable in all cases. Good wire is the most perfect material for ropes.

TABLE XXXII.—*Resistance to Crushing.*

A cube of $1\frac{1}{2}$ inch side was crushed—

Chalk ..... pounds	1,127
Brick	1,265
" hard burnt	3,200
Sandstone	7,070
Marble	13,600
Limestone	17,350

One cubic inch of—

Boxwood	20,000
Oak	17,000
Pine	12,000
Brass	10,304
Cast-iron	86,397
Granite	10,910

A cube of ½ inch side of cast-iron was broken—

	Lbs.	Lbs.
Soft cast-iron	1,439, or to the sq. in.	92,138
" 2 heights	2,116	135,424
" 3 or more h'ts,	1,758	112,524
Cubes of ½ inch	9,773	156,376
" horizontal cast,	10,114	161,826
" vertical cast	11,110	177,759
" directly cast, not cut from a large piece,		219,490
" same iron, but twice melted; once in the cupola, and once in the reverberatory furnace, and then cast into a cube of the required size		262,675

A cube of ½ inch side, soft cast-iron, heavy cast, in. 9,774
" " " light cast, " 10,114
" " " vertical cast, " 11,136

One square inch of wrought-iron, all of the same kind, was compressed by the following weights, and in the dimensions given. It was not broken, but compressed so far as to show no compression.

A cube of ½ inch side.....pounds 71,215
" ⅝ " 71,656
" ¾ " 72,900
" 1 " 71,917
A cube of steel, 1 inch 190,000

If the ends of these materials are rounded, such as balls, or props with rounded ends, the resistance is only one-third of that found by these experiments.

TABLE XXXIII.—*Dimensions of Cast-iron Columns, to sustain certain Loads with safety.*

Diameter in inches.	The length or height in feet.										
	4	6	8	10	12	14	16	18	20	22	24
	Load in Cwts.										
2	72	60	49	40	32	26	22	18	15	13	11
2½	119	105	91	77	65	55	47	40	34	29	25
3	178	163	145	128	111	97	84	73	64	56	49
3½	247	232	214	191	172	156	135	119	106	94	83
4	326	310	288	266	242	220	198	178	160	144	130
4½	418	400	379	354	327	301	275	251	229	208	189
5	522	501	379	452	427	394	365	337	310	285	262
6	607	592	573	550	525	497	469	440	413	386	360
7	1032	1013	989	959	924	887	848	808	765	725	686
8	1333	1315	1289	1259	1224	1185	1142	1097	1052	1006	959
9	1716	1697	1672	1640	1603	1561	1515	1467	1416	1364	1311
10	2119	2100	2077	2045	2007	1964	1916	1865	1811	1755	1697
11	2570	2550	2520	2490	2450	2410	2358	2305	2248	2189	2127
12	3060	3040	3020	2970	2930	2900	2830	2780	2730	2670	2600

TABLE XXXIV.—*Strength of Materials to resist Pressure, calculated for Columns.*

If the resistance of material to crushing is 1, then a column, whose thickness is to its height as the following numbers, will carry, if of wrought-iron—

Thickness to Length.	Resistance.
$\frac{1}{24}$	$\frac{1}{2}$
$\frac{1}{36}$	$\frac{1}{4}$
$\frac{1}{72}$	$\frac{1}{10}$
$\frac{1}{120}$	$\frac{1}{25}$
$\frac{1}{144}$	$\frac{1}{36}$
$\frac{1}{216}$	$\frac{1}{81}$

For cast-iron—

$\frac{1}{4}$	$\frac{2}{3}$
$\frac{1}{8}$	$\frac{1}{2}$
$\frac{1}{36}$	$\frac{2}{15}$

The same law applied to timber—

Height of column to thickness.	Resistance.
1	1
12	$\frac{5}{6}$
24	$\frac{1}{2}$
36	$\frac{1}{3}$
48	$\frac{1}{5}$
60	$\frac{1}{12}$
72	$\frac{1}{24}$

TABLE XXXV.—*Relative Resistance of Material to Crushing, to Rupture by Tension, and to Rupture by cross Strain.*

Material.	Assumed resistance to crushing, sq. in.	Resistance of rupture to tension, sq. in.	Traverse strength of 1 in. sq. bar, 1 foot long.
Timber	1000	1900	85·1
Cast-iron	"	158	19·8
Stone	"	100	9·8
Glass	"	123	10

TABLE XXXVI.— *Weight and Pressure which a Cast-iron Beam of* 1 *inch will support, without destroying its elastic force, when it is supported at each end, and loaded in the middle of its length; also, the deflection in the middle which that weight will produce.*

Depth.	SIX FEET.		SEVEN FEET.		EIGHT FEET.		NINE FEET.		TEN FEET.	
	Weight.	Defl'n	Weight.	Defl'n	Weight.	Defl'n	Weight.	Defl'n	W't.	Defl'n
Inches.	Lbs.	In.	Lbs.	In.	Lbs.	In.	Lbs.	In.	Lbs.	In.
3	1278	·24	1089	·33	954	·42	855	·54	765	·66
4	2272	·18	1936	·24	1700	·32	1520	·40	1360	·05
5	3560	·14	3050	·19	2650	·25	2375	·32	2125	·04
6	5112	·12	4356	·16	3816	·21	3420	·27	3060	·33
7	6958	·10	5929	·14	5194	·18	4655	·23	4165	·29
8	9088	·09	7744	·12	6784	·16	6080	·20	5440	·25
9	——	—	9801	·10	8586	·14	7695	·18	6885	·22
10	——	—	12100	·09	10600	·12	9500	·16	8500	·02

TABLE XXXVII.—*Diameter of Journals, in inches, for Cast-iron.*

Horse-power.	Number of revolutions per minute.																	
	10	20	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105
4	5·5	4·5	3·7	3·8	3·5	3·3	3·2	3·1	·3	2·9	2·9	2·8	2·7	2·7	2·6	2·6	2·6	2·5
6	6·3	5	4·4	4.1	4	3·8	3·7	3·6	3·5	3·5	3·4	3·3	3·2	3·2	3	3	2·9	2·9
8	6·9	5·5	4·8	4·6	4·4	4·2	4·1	4	3·9	3·8	3·7	3·6	3·5	3·5	3·4	3·4	3·3	3·2
10	7·4	5·9	5·2	4·9	4·7	4·6	4·4	4·2	4·1	4	3·9	3·8	3·7	3·7	3·6	3·6	3·5	3·4
12	7·9	6·3	5·6	5·4	5·2	5	4·8	4·6	4·4	4·3	4·2	4·1	4	3·9	3·8	3·8	3·7	3·6
16	8·7	7·1	6·1	5·8	5·6	5·4	5·2	5	4·8	4·7	4·6	4·5	4·4	4·4	4·2	4·2	4·1	4
20	9·3	7·4	6·6	6·4	5·9	5·7	5·6	5·4	5·2	5·1	5	4·8	4·6	4·6	4·5	4·5	4·4	4·4
25	10	8	7·1	6·8	6·3	6	5·9	5·6	5·5	5·4	5·3	5·2	5·1	4·9	4·8	4·7	4·6	4·6
30	10·7	8·4	7·4	7·1	6·9	6·7	6·5	6·3	5·9	5·8	5·7	5·6	5·5	5·3	5·2	5·1	5	4·9
35	11·4	8·9	7·9	7·4	7·1	6·9	6·6	6·5	6·3	6·1	5·9	5·7	5·6	5·5	5·4	5·3	5·2	5·2
40	11·7	9·3	8·3	7·8	7·4	7·2	6·9	6·7	6·6	6·4	6·2	6	5·9	5·8	5·7	5·6	5·6	5·5
45	12	9·7	8·7	8·1	7·6	7·4	7	6·8	6·9	6·5	6·4	6·2	6·1	6	5·9	5·8	5·7	5·6
50	12·6	10	9	8·5	8	7·8	7·4	7·3	7·2	6·9	6·8	6·6	6·5	6·4	6·2	6	5·9	5·8
60	13·6	10·8	9·3	9	8·6	8·2	7·7	7·6	7·4	7·3	7·2	6·9	6·8	6·8	6·7	6·6	6·4	6·2

In practice it is advisable to increase the size noted in this table; not because the dimensions are not sufficient, but on account of the varying in the quality of iron.

TABLE XXXVIII.— *Width of Belts, in inches, required to transmit a certain number of Horse-powers.*

The velocity of these belts is assumed to be from 25 to 30 feet per second. Where belts are short, the power should be transmitted by gearing.

Horse-powers.	SMALLEST DIAMETER OF THE DRUM OR PULLEY IN FEET.								
	2	3	4	5	6	7	8	9	10
1	1·8	1·2	·9	·7	·6	·5	·4	·4	·3
2	3·6	2·4	1·8	1·4	1·2	1	·9	·8	·7
3	5·4	3·6	2·7	2·1	1·8	1·5	1·3	1·2	1
4	7·2	4·8	3·6	4·8	2·4	2	1·8	1·6	1·4
5	9	6	4·5	3·6	3	2·5	2·2	2	1·8
7	12·6	8·4	6·3	5·4	4·2	3·5	3·7	2·8	2·5
10	18	12	9	7·2	6	5·1	4·5	4	3·6
12	21·6	14·4	10·8	8·6	7·2	6·1	5·4	4·8	4·3
14	25·2	16·8	12·6	10	8·4	7·1	6·3	5·6	5
16	28·8	19·2	14·4	11·5	9·6	8·2	7·2	6·4	5·7
18	32·4	21·6	16·2	12·9	10·8	9·2	8·1	7·2	6·4
20	36	24	18	14·4	12	10·2	9	8	7·2
25	45	30	22·5	18	15	12·8	11·2	10	9
30	54	36	27	21	18	15	13	12	10
40	72	48	36	28	24	20	18	16	14
50	90	60	45	36	30	25	22	20	18
60	108	72	54	43	36	30	27	24	21
70	126	84	63	50	42	35	31	28	25
80	144	96	72	57	48	41	36	23	28
90	162	108	81	64	54	46	40	36	32
100	180	120	90	72	60	51	45	40	36

If the belts are wider than 1·5 feet, the whole may be divided into small belts of a convenient size.

A leather belt ought to have a velocity of at least 1500 feet per minute, and not more than 2000 feet, or it does not last long. If the tightening pulley is used too strong, it increases friction in the gudgeons of the shaft, and prematurely destroys the belt.

TABLE XXXIX.—*Ductility and Malleability of Metals.*

Alphabetical order in which metals are ductile and malleable.	Brittle metals in alphabetical order.	Metals in the order of their wire-drawing ductility.	Metals in the order of their laminable ductility.
Cadmium	Antimony	Gold	Gold
Copper	Arsenic	Silver	Silver
Gold	Bismuth	Platinum	Copper
Iron	Cerium	Iron	Tin
Iridium	Chromium	Copper	Platinum
Lead	Cobalt	Zinc	Lead
Magnesium	Columbium	Tin	Zinc
Mercury	Iridium	Lead	Iron
Nickel	Manganese	Nickel	Nickel
Osmium	Molybdenum	Palladium	Palladium
Palladium	Osmium	Cadmium	Cadmium
Platinum	Rhodium		
Potassium	Tellurium		
Silver	Titanium		
Sodium	Tungsten		
Tin	Uranium		
Zinc			

TABLE XL.—*To ascertain the Weight of Metal Pipes.*

Thickness in parts of inches.	Wrought Iron.	Copper.	Lead.
$\frac{1}{32}$	·326	11½ lbs. plate 38	2 lbs. lead ·483
$\frac{1}{16}$	·633	23½ " ·76	4 " ·967
$\frac{3}{32}$	·976	35 " 1·14	5½ " 1·45
$\frac{1}{8}$	1·3	46½ " 1·52	8 " 1·933
$\frac{5}{32}$	1·627	58 " 1·9	9¼ " 2·417
$\frac{3}{16}$	1·95	70 " 2·26	11 " 2·9
$\frac{7}{32}$	2·277	80½ " 2·66	13 " 3·383
$\frac{1}{4}$	2·6	93 " 3·04	15 " 3·867

USE OF THIS TABLE.—To the interior diameter of the pipe in inches, add the thickness of the metal; multiply the sum by the decimals opposite the thickness, and under the name of the metal; multiply by the length of the pipe in feet, and the product is the weight in pounds.

TABLE XLI.—*Weight of Cast-iron Pipes of various thicknesses.*

Core	¼ inch.	⅜ inch.	½ inch.	⅝ inch.	¾ inch.	⅞ inch.	1 inch.	1⅛ inch.	1¼ inch.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1 in.	3·1	5·1	7·4	10	12·9	16·1	19·6	23·5	27·6
1¼	3·7	6	8·6	11·5	14·7	18·3	22·1	26·2	30·7
1½	4·3	6.9	9·8	13	16·6	20·4	24·5	29	33·7
1¾	4·9	7·8	11·1	14·6	18·4	22·6	27	31·8	36·8
2	5·5	8·8	12·3	16·1	20·3	24·7	29 5	34·5	39·9
2¼	6·7	10·6	14·7	19·2	23·9	28·9	34·4	40	46
3	8	12·4	17·2	22·2	27·6	33·3	39·3	45·6	52·2
3½	9·2	14·2	19·6	25·3	31·3	37·6	44·2	51·1	58·3
4	10·4	16·1	22·1	28·4	35	41·9	49·1	56·6	64·4
4½	11·7	18	24·5	31·4	38·7	46·2	54	62·1	70·6
5	12·9	19·8	27	34·5	42·3	50·5	58·9	67·6	76·7
6	15·3	23·5	31·9	40·7	49·7	59·1	68·7	78·7	88·8
7	17·8	27·2	36·8	46·8	56·8	67·7	78·5	89·7	101·2
8	20	30·8	41·7	52·9	64·4	76·2	88·4	100·8	113·5
9	22·7	34·5	46·6	59·1	71·8	84·8	98·2	111·8	125·8
10	25·2	38·2	51·5	65·2	79·2	93·4	108	122·8	138·1
11	27·6	41·9	56·5	71·3	86·5	102	117·8	133·9	150·3
12	30·1	45·6	61·4	77·5	93·6	110·6	127·6	145	162·6

TABLE XLII.—*Weight of a Superficial Foot of Plate, or Sheet, in pounds; the thickness measured by the Wire Gauge.*

No.	Iron.	Copper.	Brass.	No.	Iron.	Copper.	Brass.
1	12·5	14·5	13·7	12	4·3	5	4·8
2	12	13·9	13·2	13	3·7	4·3	4·1
3	11	12·7	12·1	14	3·1	3·6	3·4
4	11	11·6	11	15	2·8	3·2	3·1
5	8·7	10·1	9·6	16	2·5	2·9	2·7
6	8·1	9·4	8·9	17	2·1	2·5	2·4
7	7·5	8·7	8·2	18	1·8	2·1	2
8	6·8	7·9	7·5	19	1·7	1·9	1·8
9	6·2	7·2	6·8	20	1·5	1·7	1·6
10	5·6	6·5	6·1	21	1·4	1·6	1·5
11	5	5·8	5·5	22	1·2	1·4	1·3
				23	1·1	1·3	1·2

TABLE XLIII.—*Weight of a Cubic Inch of Metal.*

One cubic inch of	lead weighs	·4103	pounds.
"	copper	·3225	"
"	brass	·3037	"
"	iron, wrought	·2790	"
"	" cast	·2630	"
"	tin	·2636	"
"	zinc	·2600	"

The weight of a cubic inch of water is ·03617 pounds.

TABLE XLIV.—*Comparative Weight of Metals.*

Wrought-iron being taken as 1, cast-iron is ·95, steel 1·02, copper 1·16, brass 1·09, and lead 1·48.

TABLE XLV.—*Weight of various Substances.*

	One cubic foot, in lbs.	One cubic inch, in lbs.
Cast-iron	450·55	·2607
Wrought-iron	486·65	·2816
Steel	489·08	·2834
Copper	555	·3211
Lead	708·75	·4101
Brass	537·75	·3112
Tin	456	·2630
White pine	29·56	·0171
Sea-water	64·03	·0372
Water	62·05	·0361
Air	·07529	
Steam	·03689	

TABLE XLVI.—*Value of Fuel.*

Material.	Pounds of water heated from 32° to 212°, by lbs.	Water evaporated in pounds, by 1 lb. of fuel.	Weight of atm'c air at 32° required to burn 1 lb. of fuel.
Kiln-dried wood	35	6·36	5·96
Air-dried "	26	4·72	4·47
Wood charcoal	73	13·27	11·46
Soft stone-coal	60	10·99	9·26
Anthracite	69	12·04	12
Coke	65	11·81	11·46
Carb'd hydrogen	76	13·81	14·58
Oil, wax or tallow	78	14·18	15
Alcohol	52	9·56	11·60
Turf	30	5·45	4·60

TABLE XLVII.—*Dimensions of Cogs, Pitch and Speed of Wheels.*

Pitch, in inches.	Thickness, in inches.	Breadth, in inches.	Length, in inches.	Horse-pow'r by 2·27 feet speed.	H'rse-power by 3 feet speed.	H'rse-power by 6 feet speed.
4·20	2	10	2·40	13·33	17·61	35·23
3·99	1·9	9·5	2·28	13·03	15·90	31·80
3·78	1·8	9	2·16	10·80	14·27	28·54
3·57	1·7	8·5	2·04	9·63	17·72	25·54
3·36	1·6	8	1·92	8·53	11·27	22·54
3·15	1·5	7·5	1·80	7·50	9·91	19·82
2·94	1·4	7	1·68	6·53	8·63	17·26
2·73	1·3	6·5	1·56	5·63	7·44	14·88
2·52	1·2	6	1·44	4·80	6·34	12·68
2·31	1·1	5·5	1·32	4·03	5·32	10·64
2·10	1	5	1·20	3·33	4·40	8·81
1·89	·9	4·5	1·08	2·70	3·57	7·14
1·68	·8	4	·96	2·13	2·81	5·62
1·47	·7	3·5	·84	1·63	2·15	4·30
1·26	·6	3	·72	1·20	1·59	3·18
1·05	·5	2·5	·60	·83	1·10	2·20

TABLE XLVIII.—*Relative Value of Fuel, by Weight.*

Dry wood charcoal	705	Impure stone-coal	590
Common "	600	Kiln-dried wood	366
Pure coke	705	Air-dried "	294
" soft stone-coal	705		

TABLE XLIX.—*Relations of Motion to Time, in the free Descent of Bodies by Gravity.*

Time in sec'ds	1	2	3	4	5	6	7	8	9	10
Velocities	$1g$	$2g$	$3g$	$4g$	$5g$	$6g$	$7g$	$8g$	$9g$	$10g$
Spaces	$1\frac{g}{2}$	$4\frac{g}{2}$	$9\frac{g}{2}$	$16\frac{g}{2}$	$25\frac{g}{2}$	$36\frac{g}{2}$	$49\frac{g}{2}$	$64\frac{g}{2}$	$81\frac{g}{2}$	$100\frac{g}{2}$
Difference	$1\frac{g}{2}$	$3\frac{g}{2}$	$5\frac{g}{2}$	$7\frac{g}{2}$	$9\frac{g}{2}$	$11\frac{g}{2}$	$13\frac{g}{2}$	$15\frac{g}{2}$	$17\frac{g}{2}$	$19\frac{g}{2}$

The letter g means the free descent at the end of the first second, or 32·22 feet.

TABLE I.—*Square and Cube Roots of Numbers.*

No.	S. R.	C. R.	No.	S. R.	C. R.	No.	S. R.	C. R.	No.	S. R.	C. R.
1	1·0000	1·0000	55	7·4161	3·8029	109	10·4403	4·7768	163	12·7671	5·4625
2	1·4142	1·2599	56	7·4833	3·8258	110	10·4880	4·7914	164	12·8062	5·4737
3	1·7320	1·4422	57	7·5498	3·8485	111	10·5356	4·8058	165	12·8452	5·4848
4	2·0000	1·5874	58	7·6157	3·8708	112	10·5830	4·8202	166	12·8840	5·4958
5	2·2360	1·7099	59	7·6811	3·8929	113	10·6301	4·8345	167	12·9228	5·5068
6	2·4494	1·8171	60	7·7459	3·9148	114	10·6770	4·8488	168	12·9614	5·5178
7	2·6457	1·9129	61	7·8102	3·9364	115	10·7238	4·8629	169	13·0000	5·5287
8	2·8284	2·0000	62	7·8740	3·9578	116	10·7703	4·8769	170	13·0384	5·5396
9	3·0000	2·0800	63	7·9372	3·9790	117	10·8166	4·8909	171	13·0766	5·5404
10	3·1622	2·1544	64	8·0000	4·0000	118	10·8627	4·9048	172	13·1148	5·5612
11	3·3166	2·2239	65	8·0622	4·0207	119	10·9087	4·9186	173	13·1529	5·5720
12	3·4641	2·2894	66	8·1240	4·0412	120	10·9544	4·9324	174	13·1909	5·5827
13	3·6055	2·3513	67	8·1853	4·0615	121	11·0000	4·9460	175	13·2287	5·5934
14	3·7416	2·4101	68	8·2462	4·0816	122	11·0453	4·9596	176	13·2664	5·6040
15	3·8729	2·4662	69	8·3066	4·1015	123	11·0905	4·9731	177	13·3041	5·6416
16	4·0000	2·5198	70	8·3666	4·1212	124	11·1355	4·9866	178	13·3416	5·6252
17	4·1231	2·5712	71	8·4261	4·1408	125	11·1803	5·0000	179	13·3790	5·6357
18	4·2426	2·6207	72	8·4852	4·1601	126	11·2249	5·0132	180	13·4164	5·6462
19	4·3588	2·6684	73	8·5440	4·1793	127	11·2694	5·0265	181	13·4536	5·6566
20	4·4721	2·7144	74	8·6023	4·1983	128	11·3137	5·0396	182	13·4907	5·6670
21	4·5825	2·7589	75	8·6602	4·2171	129	11·3578	5·0527	183	13·5277	5·6774
22	4·6904	2·8020	76	8·7177	4·2358	130	11·4017	5·0657	184	13·5646	5·6877
23	4·7958	2·8438	77	8·7749	4·2543	131	11·4455	5·0787	185	13·6014	5·6980
24	4·8989	2·8844	78	8·8317	4·2726	132	11·4891	5·0916	186	13·6381	5·7082
25	5·0000	2·9240	79	8·8881	4·2908	133	11·5325	5·1044	187	13·6747	5·7184
26	5·0990	2·9624	80	8·9442	4·3088	134	11·5758	5·1172	188	13·7113	5·7286
27	5·1961	3·0000	81	9·0000	4·3267	135	11·6189	5·1299	189	13·7477	5·7387
28	5·2915	3·0365	82	9·0553	4·3444	136	11·6619	5·1425	190	13·7840	5·7488
29	5·3851	3·0723	83	9·1104	4·3620	137	11·7046	5·1551	191	13·8202	5·7589
30	5·4772	3·1072	84	9·1651	4·3795	138	11·7473	5·1676	192	13·8564	5·7689
31	5·5677	3·1413	85	9·2195	4·3968	139	11·7898	5·1801	193	13·8924	5·7789
32	5·6568	3·1748	86	9·2736	4·4140	140	11.8321	5·1924	194	13·9283	5·7889
33	5·7445	3·2075	87	9·3273	4·4310	141	11·8743	5·2048	195	13·9642	5·7988
34	5·8309	3·2396	88	9·3808	4·4479	142	11·9163	5·2171	196	14·0000	5·8087
35	5·9160	3·2710	89	9·4339	4·4647	143	11·9582	5·2293	197	14·0356	5·8186
36	6·0000	3·3019	90	9·4868	4·4814	144	12·0000	5·2414	198	14·0712	5·8284
37	6·0827	3·3322	91	9·5393	4·4979	145	12·0415	5·2535	199	14·1067	5·8382
38	6·1644	3·3619	92	9·5916	4·5143	146	12·0830	5·2656	200	14·1421	5·8480
39	6·2449	3·3912	93	9·6436	4·5306	147	12·1243	5·2776	201	14·1774	5·8577
40	6·3245	3·4199	94	9·6953	4·5468	148	12·1655	5·2895	202	14·2126	5·8674
41	6·4031	3·4482	95	9·7467	4·5629	149	12·2065	5·3014	203	14·2478	5·8771
42	6·4807	3·4760	96	9·7979	4·5788	150	12·2474	5·3132	204	14·2828	5·8867
43	6·5574	3·5033	97	9·8488	4·5947	151	12·2882	5·3250	205	14·3178	5·8963
44	6·6332	3·5303	98	9·8994	4·6104	152	12·3288	5·3368	206	14·3527	5·9059
45	6·7082	3·5568	99	9·9198	4·6260	153	12·3693	5·3484	207	14·3874	5·9154
46	6·7823	3·5830	100	10·0000	4·6415	154	12·4096	5·3601	208	14·4222	5·9249
47	6·8556	3·6088	101	10·0498	4·6570	155	12·4498	5·3716	209	14·4568	5·9344
48	6·9282	3·6342	102	10·0995	4·6723	156	12·4899	5·3832	210	14·4913	5·9439
49	7·0000	3·6593	103	10·1488	4·6875	157	12·5299	5·3946	211	14·5258	5·9533
50	7·0710	3·6840	104	10·1980	4·7026	158	12·5698	5·4061	212	14·5602	5·9627
51	7·1414	3·7084	105	10·2469	4·7176	159	12·6095	5·4175	213	14·5945	5·9720
52	7·2111	3·7325	106	10·2956	4·7326	160	12·6491	5·4288	214	14·6287	5·9814
53	7·2801	3·7562	107	10·3440	4·7474	161	12·6885	5·4401	215	14·6628	5·9907
54	7·3484	3·7797	108	10·3923	4·7622	162	12·7279	5·4513	216	14·6969	6·0000

To find the Square or Cube Root of a Number consisting of Integers and Decimals.

Rule.—Multiply the difference between the root of the integer part of the given number, and the root of the next higher number, by the decimal part of the given number, and add the product to the root of the given integer number; the sum is the root required.

Ex.—Required the square root of 20·321.

Square root of 21 = 4·5825
" " 20 = 4·4721.
Diff. = ·1104 × ·321 + 4·4721 = 4·507, &c., the root required.

TABLE LI.—*Area of Polygons, for a side of One; that is, One Foot, or Inch, or Yard, &c.*

For a triangle, (of equal sides).....	·433
" quadrate	1·000
" 5-sided polygon.....	1·720
" 6 " "	2·598
" 7 " "	3·634
" 8 " "	4·828
" 9 " "	6·182
" 10 " "	7·694
" 11 " "	9·366
" 12 " "	11·196

The area is found, by multiplying the square of one of the sides of the polygon by the corresponding number in the table.

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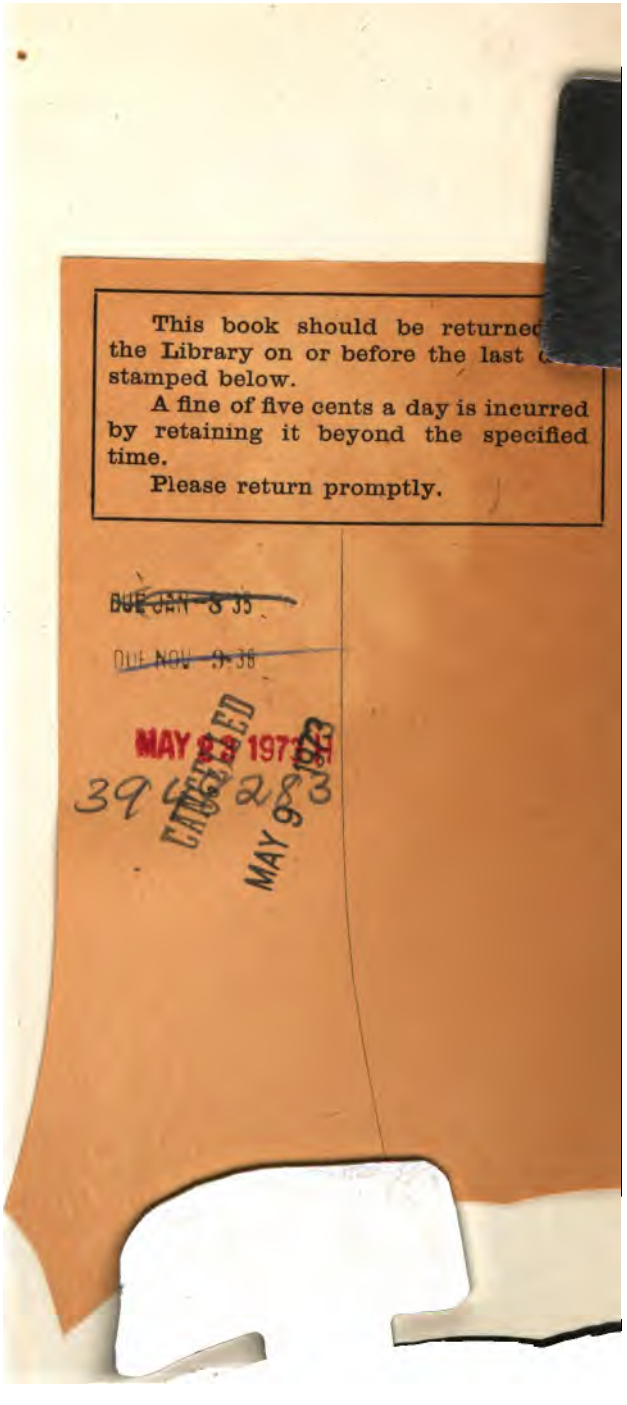
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